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NASA-USRA ADVANCED SPACE DESIGN PROJECT

A GEOSYNCHRONOUS SPACE STATION: YEAR 2005

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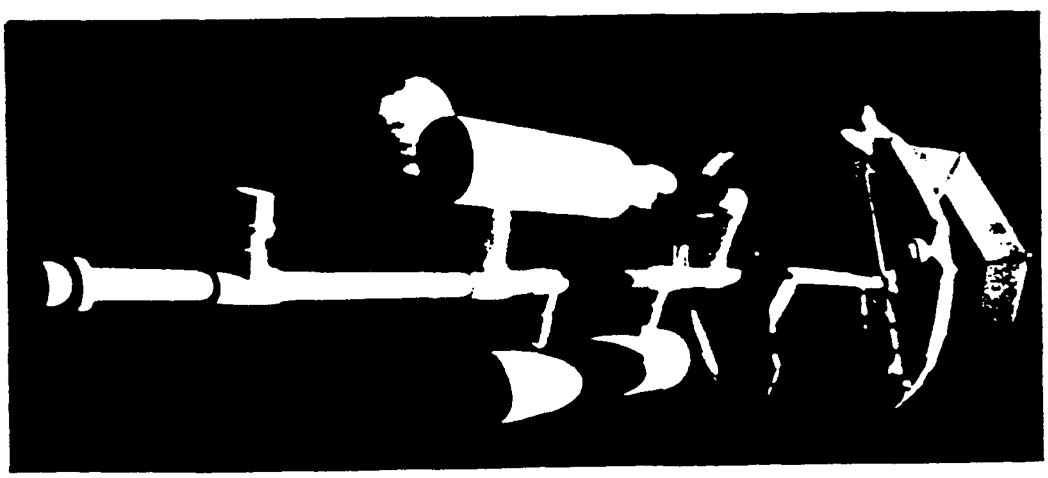

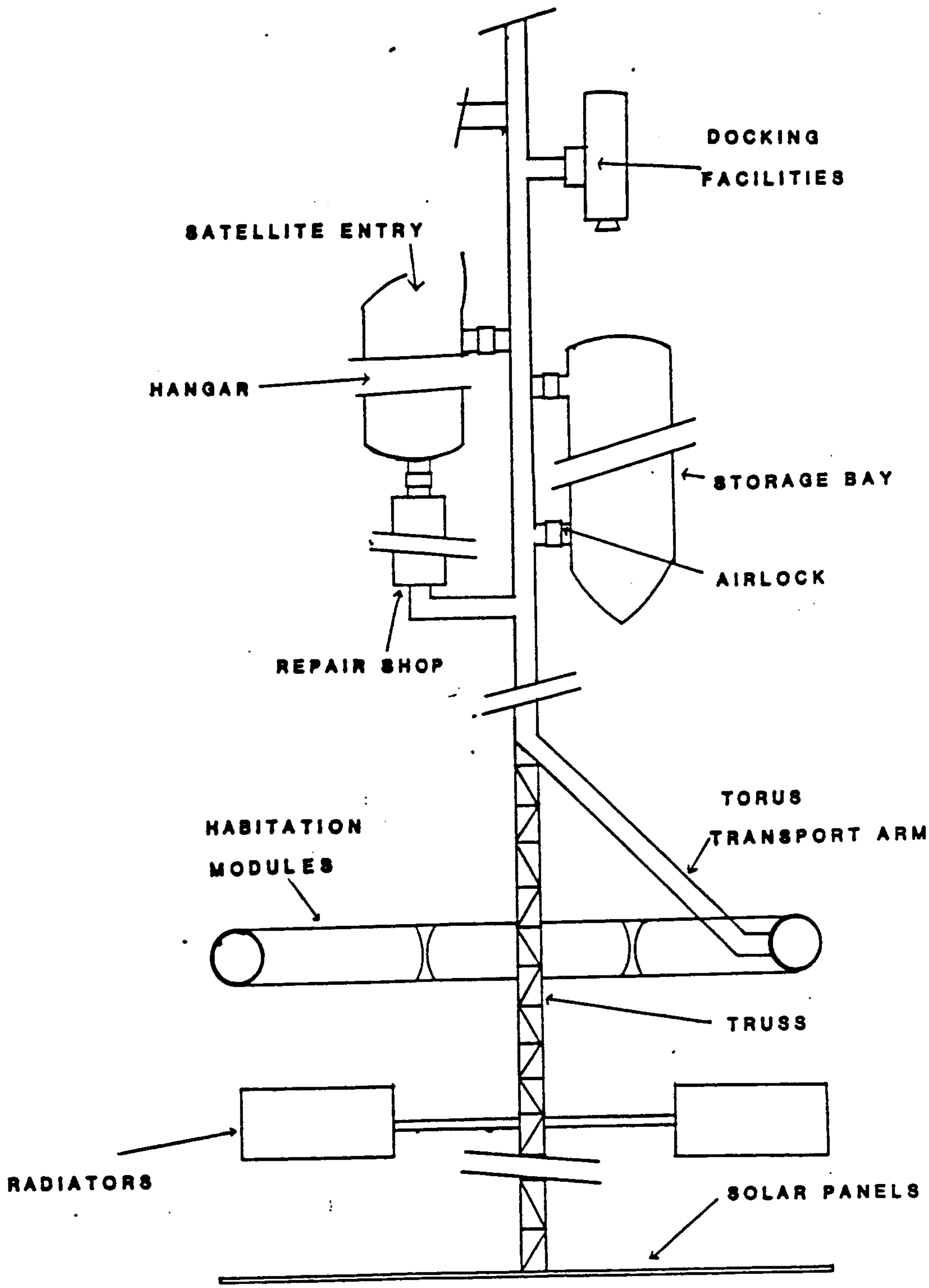

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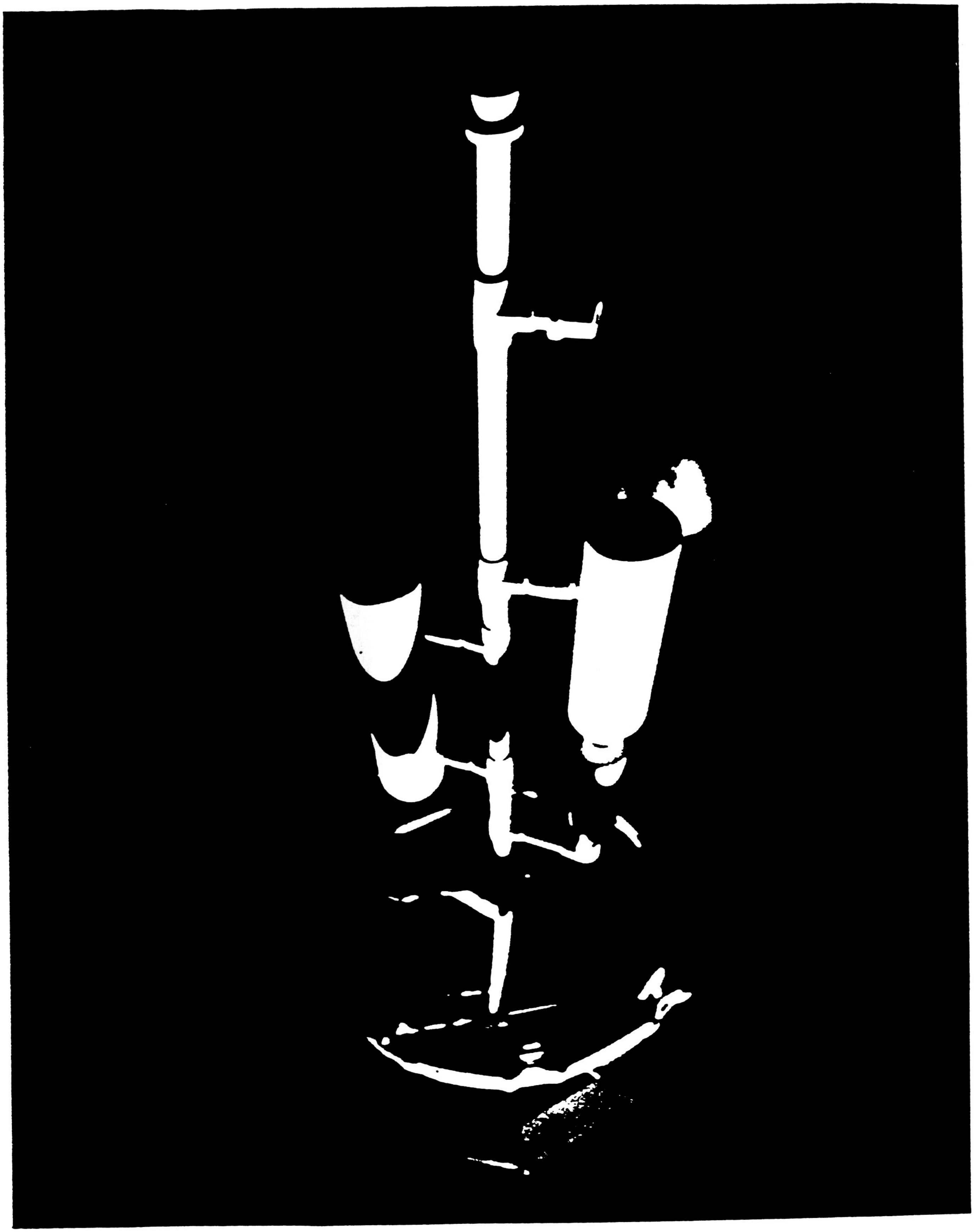

Geosynchronous Space Station

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A Geosynchronous Space Station

The creation, development and fabrication of a space station in geosynchronous orbit is a necessary intermediate step to the safe and orderly progression of manned space exploration. While satisfying the demands of earth-bound economic systems through a variety of "looking down" technologies, the geosynchronous space station, at the edge of space, provides a wide range of "looking outward" possibilities and an optional staging base for planetary as well as deep space ventures. As the LEO space station resides near earth forming the first step toward atmospheric and gravitational escape, the GEO station will reside at the junction between Earth and space -- a last step off and away from Earth. From GEO, the rigors and demands of a true space existence can be met and solved prior to a full commitment to such uncharted human endeavor.

Before we begin to address specific design questions related to GEO station, it is necessary to envision the type and amounts of activity that are likely to be undertaken by GEO station.

One of the primary functions of a GEO station will be servicing of satellites. A significant number of satellites and satellite related material already exist in geosynchronous or drifting geosynchronous orbits. The NORAD Catalog 1982 lists 75 satellites in geosynchronous and 143 satellites in drifting geosynchronous orbits. Of these 218 satellites, 42 are totally disabled. Also, smaller pieces of material are known to be adrift in geosynchronous orbit. Thus, approximately two-thirds of the satellites in geosynchronous orbit need to be removed from orbit, refurbished or stabilized in orbit. GEO orbits, especially in the more desirable longitudes, are crowded and cluttered. These orbits must be cleared to make room for both existing and future operational satellites.

Aside from the obvious advantages of on-site satellite servicing, the presence of GEO station must be compared to similar services made available from LEO station. Whereas LEO activities at geosynchronous orbit distances require a sizeable commitment to propulsion and guidance systems in a reusable orbital transfer vehicle (OTV), similar activities conducted from GEO station would require a modest orbital maneuvering vehicle (OMV) using small amounts of fuel and minor guidance systems. Space junk in GEO orbits could be retrieved and reutilized by a GEO station thus accomplishing two prime mission tasks; clean up of geosynchronous orbits and fabrication or refurbishing of operational satellites. All of this could be achieved without paying the price of ascending and descending the "gravity well" that exists between LEO and GEO orbits. Also, a GEO orbit OMV could serve to locate, map and police the drifting orbits of space junk to prevent collisions with operational satellites or even the GEO station, itself.

GEO station will also be a focal point for communications. Activities such as earth communication relays, surveillance of earth resources and human impacts, weather prediction and monitoring, site localization and military surveillance can be supported using an antennae farm in geosynchronous orbit. The fabrication, operation and repair of large antenna could be accomplished from the GEO station itself. Laser ranging and discrete laser communication channels can be achieved. If attention is directed outward, a wide range of astronomical activities are possible, deep space communication is much enhanced and a space control station for both manned and unmanned interplanetary spacecraft seems both highly desirable and quite feasible.

The above applications can suffice to carry much of the initial cost of a GEO station as well as the continuing operational costs. As will be seen later, many other GEO station activities will help bear the cost burden of GEO. Yet, GEO station provides a unique opportunity for science and technology developments crucial to the continuing development of a space program.

A geosynchronous orbit, at the edge of space, offers a multitude of science opportunities not currently enjoyed and not possible from LEO station. Virtually every science area can be impacted -- geophysical, astrophysical, astronomical and even life sciences. Long observation periods, large synthetic apertures, large baselines and a hostile radiation belt make this an excellent research environment for scientists. These possibilities do not exist for LEO station. And, given the appropriate conditions of autonomy, it is likely that a whole class of new science opportunities will arise with the advent of GEO.

Many applications and technological activities for science could also be explored while working aboard the space station. The technologies used for satellite refurbishing, for reutilization and for fabrication can be carried over to various science technologies. Rather than abandon old experimental apparatus and ignore space junk, the GEO station will seek means for processing materials such that most mass is conserved. Reprocessed junk, science experiments, asteroid material, and lunar material will be the basis for new fabrications using robotic machining and assembly methods. Serious attention will be given to biomaterials and structures, as well. The whole applications and technologies effort will emphasize conservation activities since it is clear that eventual deep space manned missions will depend upon such conservation.

Another potentially important and profitable use of the space station is for manufacturing and material processing. The GEO station provides an opportunity to support manufacturing technologies with a variety of raw materials unavailable to LEO station. Gravity free technologies can be put in place with ore processing and material recovery challenges very different from those experienced at LEO station. Solar cell technology will grow and new VLSI circuit fabrication techniques will abound.

Both the processes to create "stock" materials and the actual forming and fitting of these materials will be achieved. A work bay and satellite recovery bay can be used for satellite refurbishing, initially, and for fabrication eventually. Asteroid and lunar materials will be processed with an eventual tremendous savings over conventional material use in the fabrication of large space structures as well as deep space vehicles and probes.

A GEO space station could also be used for surveillance, having both military and commercial-industrial applications. The simple fact of continuous monitoring of the earth's surface yields significant military advantages. Also, such monitoring can aid in industrial and commercial planning. Changing weather, altered agricultural productivity, and even a variety of mining activities can be monitored. Environmental and social disasters could be evaluated and reacted to in very rapid, definite ways. Aside from crop monitoring, insect infestations, weather monitoring and disaster evaluation, the GEO station could aid in water and air monitoring, ocean utilization and global habitability monitoring. Further, air traffic, ship traffic and even ground transportation could be identified, monitored and controlled. Finally, assurance of military compliance with treaty guidelines should aid in implementing better international relations. Neither active offensive or defensive roles for the military seem appropriate since a GEO station, like LEO station, is readily neutralized.

The space station would be invaluable as a technical proving ground.

Notably, GEO station can test the technical accomplishments of LEO to ascertain the usefulness of such technologies in a deep space setting. Also, technologies related to meteoroid shielding and radiation protection can be developed in GEO orbit with the expectation that this space environment best simulates deep space. Other technologies can be developed on a need and "boot-strap" basis; additional power systems, useful robotics and induced radial acceleration gravity are likely candidates for such developmental expansion. Finally, the remote and long duration periods in GEO station will test the adequacy of biomedical systems as well as psychosocial systems.

The hostile environment of geosynchronous orbit makes extraordinary demands not easily buffered by the proximity of earth. Thus, GEO station exemplifies the best simulation of interplanetary space yet affords emergency access, if needed, to the hospitality of earth. In such an environment, the GEO station must support long term habitation without sacrifice of the human productivity or human creativity so much desired in manned space activities. These conditions must be met without exceedingly high payload costs. At least one new technology, a Controlled Ecological Life Support System (CELSS), should be evolved to preserve mass. The need for a CELSS in GEO station is not great but to have such a system is a first step to station independence. Long term space habitation will, undoubtedly, call for a CELSS. Manned spacecraft visits to other planets can be more desirable with a good CELSS. And, a large GEO station with a fully operational CELSS can provide an alternative to life aboard spacecraft Earth.

In the not too distant future, when space exploration becomes feasible, the GEO station would be an excellent staging site and quarantine area. Since the GEO station would be at the edge of deep space, it could serve as a place to assemble interplanetary vehicles and probes. GEO station could eventually become a model for "stand-away" science and exploration stations which could be moved to proximity with asteroids and, even, neighboring planets. GEO station can, of course, be the stopover site for returning space flights from lunar and/or planetary missions. As such, a range of retrofit services, resupply activities and quarantine roles can be accommodated:

(1) Assembly of space vehicles and probes in GEO orbit would eliminate manystructural needs and propulsion wastes encountered by such systems if they were constructed on Earth. Critical components, newly installed or retrofits, could be manufactured on earth or in LEO station. But overall, the largest amount of vehicle mass could be kept away from the special needs and large expense of descending and ascending the gravity wall.

(2) As a model for other planetary or asteroid monitoring stations, GEO station would represent the development of true space technology to a point of confidence and unassailed self-sufficiency. A modern GEO station clone could be built on site and could be pulled out of orbit to undertake new interplanetary endeavors.

(3) The presence of GEO station will allow lunar vehicles as well as other manned space vehicles a reaclimation and resocialization point near earth. The biomedical adaptations necessary for returning to Earth could be achieved and exposure to the pace of Earth life could be done slowly. Importantly, the ever present possibility of earth contamination could be much reduced by the transfer of crew personnel to a shuttle used exclusively for the purpose of crew transfer. In this latter role, GEO station could serve as a biomedical/psychosocial quarantine area for personnel returning from long duration space missions.

Of course it would be presumptuous to imagine that we can currently envision all of the opportunities presented by GEO station. Mundane, but less well developed ideas are sure to emerge. Power generation sites have been proposed previously. Mirror farms could illuminate cities, increase crop growing seasons and provide emergency light for night searches in the sea or over inhospital terrain. A modest amount of station mobility could accommodate a host of other uses. But the mainstays of a GEO station design will be independence and flexibility.

Considering all of these possible functions and services of a GEO station, the question arises as to whether or not people should be resident in these activities. The cost factor of manned space activity is very large and the scope of activities that can be supported is much reduced by the need to provide for people in a space environment. It is usually argued that automation, telepresence, expert systems and robotics can suffice for most space activity. Proponents of manned space activities argue for the unmatched abilities, flexibility and ingenuity of man -- traits often required to make various space activities successful. All of these and other issues aside, it seems most compelling that the rank and file in this country simply wish to identify with the frontier traditions of exploring uncharted territories and challenges. More directly, we can identify with other people -- not with machines, robots or other fabrications of our technical and industrial world.

To date and for the immediate future it is not likely that artificial intelligence could replace people. Smart robotics are still relatively crude having poor manipulation and perception capabilities as well as crude decision making potential. Specialized, well-defined tasks can be performed rapidly, accurately and efficiently by a variety of automated systems but even modest amounts of versatility remain to be achieved by these systems.

The variety of unexpected situations that are likely to occur in a high technology circumstance such as space has already been documented in the shuttle program. Recalcitrant hardware, in waste systems or on satellites, has been fixed by astronauts. No automated robotics system could have shown the flexibility or resourcefulness that was demonstrated by the astronauts. Probability favors the continued occurrence of unexpected situations that demand the attention of people. Presumably, the use of automated systems will save astronaut time for exactly those occasions that need flexibility. Thus, maximum manned usefulness in space calls for a careful integration of manned and automated activities.

Since we envision GEO station as an enabling technology proving ground, it follows that the type and nature of activities on board must evolve toward a more comfortable presence of man in space. Opportunities for evolution are exquisitely human traits and are best recognized by humans on site. Release from the mundane tasks will allow GEO station inhabitants to use their ingenuity and creativity to fruitfully investigate new "looking down" and "looking outward" possibilities. The stresses and strains of survival can be replaced by the time for recreation, imagination and resourcefulness exercises. Given the opportunities that will be available to people in GEO station, it will be important to make this opportunity for inventiveness and creativity available to as many people as possible. In other words, the physical environment and the technical assistance will evolve such that the primary need will be for human presence and human creativity.

As far as providing a long-term desirable habitat in space, the GEO station can serve as the ultimate proving site for a self-contained, independent colony of people. Through the development of sophisticated CELSS arrangements and biomedical provisions, man can begin to live, work and thrive in a deep space environment. Miniature versions of GEO stations can then embark upon long exploration missions with the confidence that deep space problems have been mastered. These stations can be the site for dealing with a wide variety of planetary hazards and environments. And, such stations can become the means through which the resources of other planets can be tapped. The known problems of space and their solutions will be at hand whereas the unknown problems of each different surface environment will represent new challenges. Earth can't be the direct support base for all of the envisioned space activities. Nor is it likely that we will be patient with a leap frog arrangement of lunar base, then Mars base etc. We will want parallel efforts and we will want to go in many directions at once. Only the GEO station technologies and the prototypes GEO station promises will support the year 2000 plus adventures of man.

Geosynchronous Space Station?

I. GEO Station Activity Overview

	2005 Usage	2005 Revenue	2010 Usage	2010 Revenue
Scientific	2	4	1	2
Communication	1	1	3	3
Industry	3	2	4	5
Military	4	3	2	1
Satellite Serv.	1	1	4	4
Staging Base	5	5	1	2

1 = most important 5 = least important

launch year : 2005 with 10 crew members
year : 2010 will have 15-20 crew members

II. GEO Station Physical Overview

	Weight (metric tons)
Main Station	25-30
Shielding(station)	10
Gravity Module	15
Shielding(module)	5
CELSS	20
Robotics	20
Power	4

III. Differences between GEO and LEO

A. Radiation types and levels.

Predicted Dose in Rads (1 yr. in shielded, 4 lb/ft^2, workspace)

Orbit	Trapped and Cosmic rays	Solar Flares	Total
LEO (400 km, 30° inc.)	32	---	32
Geosynchronous	300	250	550

The primary particle radiations in GEO are solar protons during peak solar activity and trapped electrons. Primary cosmic rays are also significant, most notably the High Charge and Energy (HZE) particles which have a Quality Factor estimated between 12 and 40.

B. Distance

GEO = 22,236 mi.	LEO = 227 mi. ave.
35,785 km	366 km ave.
5.61 Earth Radii	0.06 Earth Radii

C. Atmosphere

	Leo	GEO
Particle Density	$10^9 cm^{-3}$	$20 cm^{-3}$
Density	$10^{13} gr.cm^{-3}$	very tiny
Temperature	600-1900 K	very cold

D. Geostationary in space

Space Station in GEO stays over the same location on the earth's surface at all times. Remote free flyers could provide continuous observation from a geostationary reference point.

Space Station in LEO orbits earth about once every 1.5 hrs.

Radiation Shielding

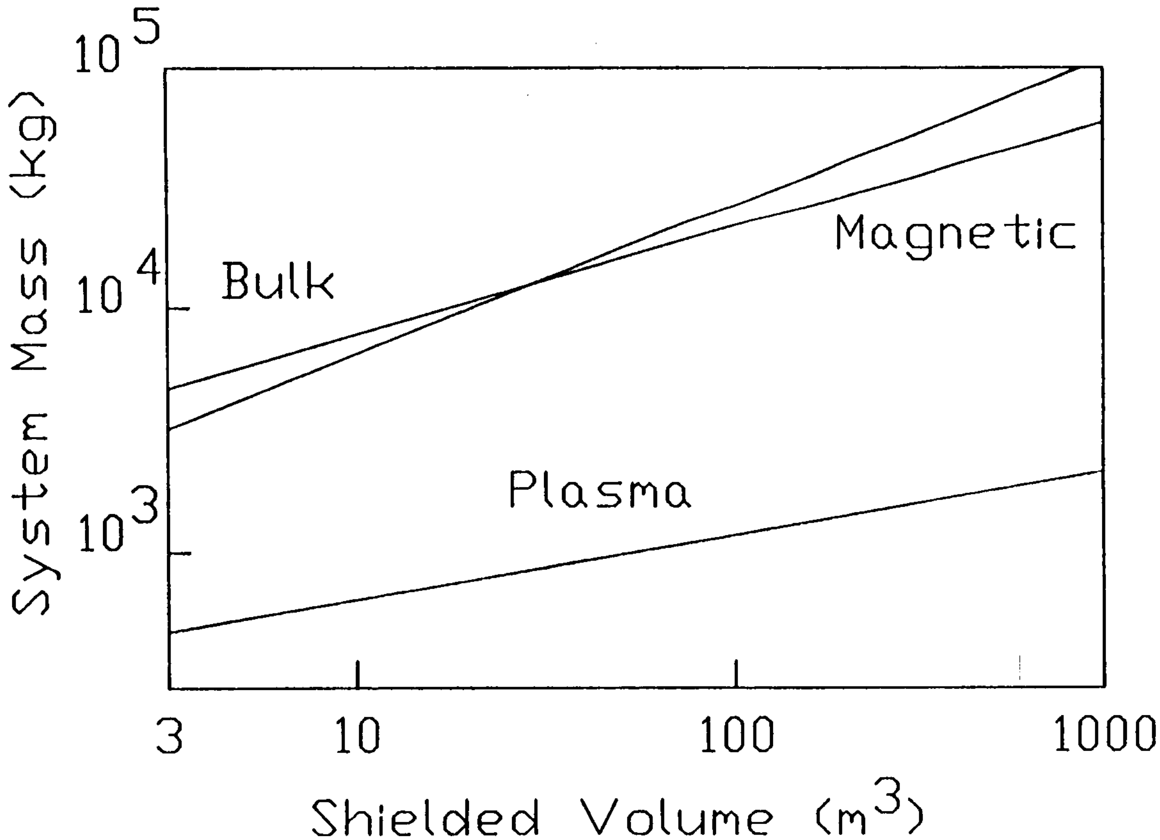
Perhaps the single most critical factor unique to a geosynchronous orbit is the inherent radiation danger. The altitude (5.61 RE) of the geosynchronous orbit overlaps with the radiation trapped in the magnetic field lines of the Van Allen belts. High energy protons, electrons, and charged nuclei of both solar and cosmic origin become concentrated along these magnetic field lines. The total lack of atmospheric filtering at GEO further increases the radiation hazard. The total predicted radiation dose for a one year exposure in GEO is 550 rads with current shielding, approximately ten times that of a LEO inclined at 90 degrees. Solar flares also present a greater danger in GEO since the station will be shielded from the sun only 64 hours each year.

Clearly, the station will have to incorporate radiation protection methods superior to the simple aluminum bulkheads now employed. This technology must be developed for manned deep space missions to become possible. The GEO station will serve as an ideal proving ground for radiation protection technologies. The options we examined in the design process included bulk, magnetic, electromagnetic, and plasma shielding.

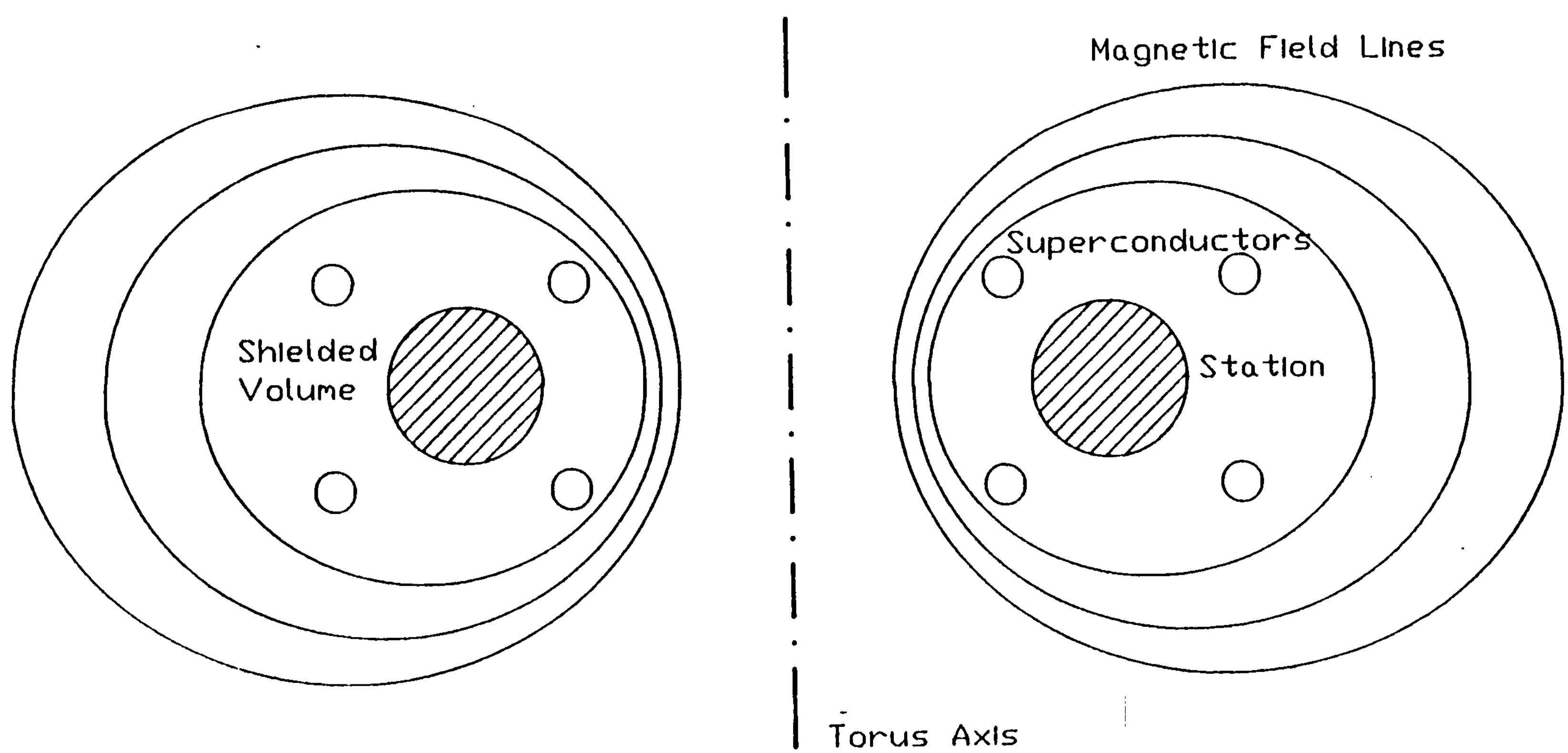
Bulk shielding, while simple and effective for all forms of radiation, exacts a high mass penalty for adequate protection required at GEO. Also, as radiation particles pass through the shielding material, Bremmstrahlung, or braking radiation, is produced (Diagram RP.1).

Magnetic shielding operates by setting up a magnetic field about the protected area. It has about a 70% weight savings over bulk shielding for large volumes such as considered here. This method produces diffuse synchrotron radiation as opposed to higher energy Bremmstrahlung radiation (Diagram RP.2).

OPTIONS FOR RADIATION SHIELDING



PLASMA SHIELDING



In electromagnetic shielding, the shielded volume is maintained at a potential difference of several million volts with respect to infinity. This voltage difference will repel particles of similar charge. However, it will attract particles of opposite charge. Since radiation with both charges exist in geosyncronous orbit, electromagnetic shielding can produce serious problems.

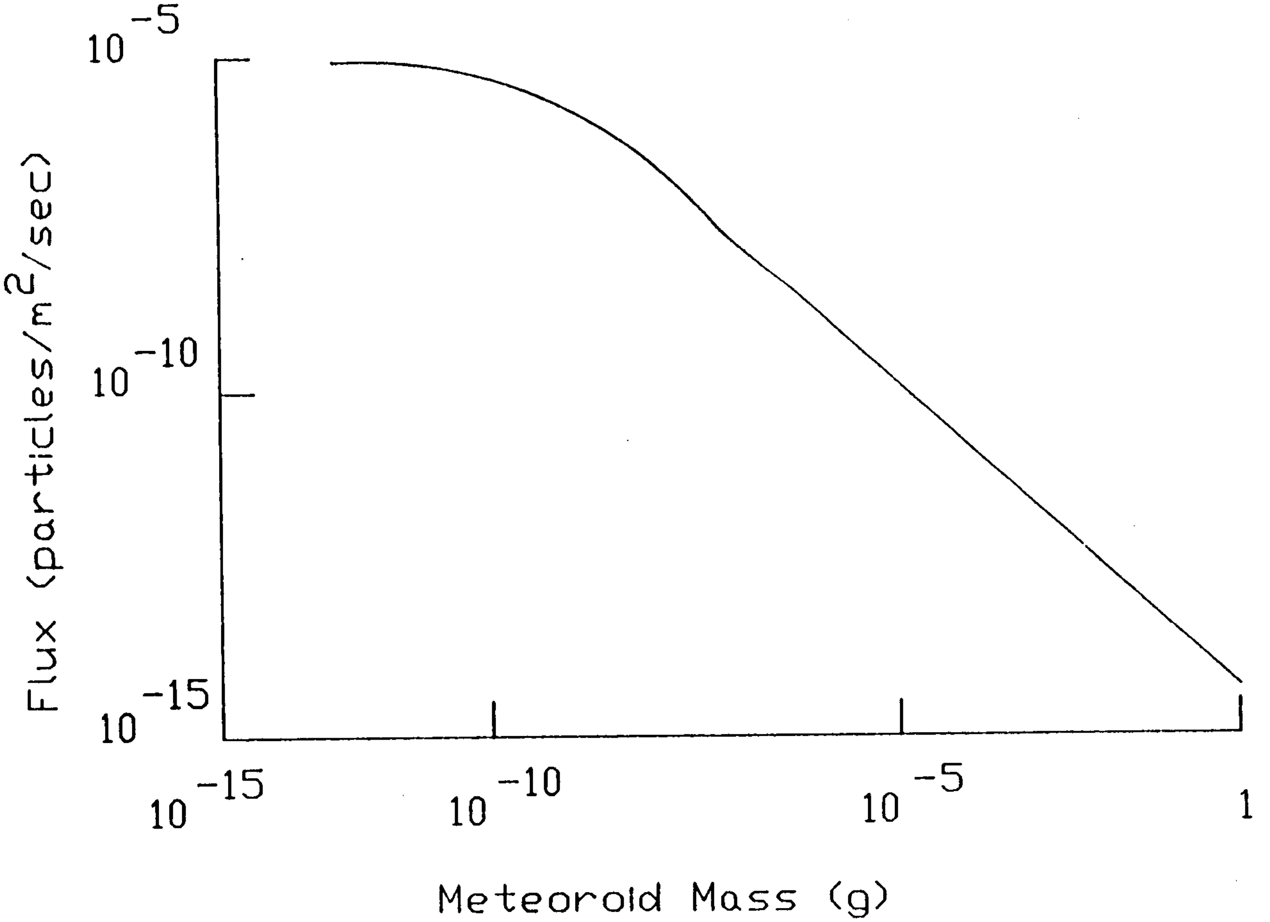
Plasma shielding, if developed to an operational stage in time to incorporate it into a GEO station, has both mass and protection advantages over the other methods discussed above. A hybrid of electrostatic and magnetic shielding, it maintains an electron cloud within magnetic field lines generated around the station by superconducting coils. Particles of both positive and negative charge are kept separate from the living environment (Diagram RP.1). However, the magnetic field restricts the station shape to a torus.

Due to mass savings, superior radiation protection, and adaptability to deep space missions, plasma shielding has been selected as the method to protect the habitability module of the GEO station. This station will have the basic shape of a torus composed of eight cylinders, 15 m long with 4.5 m diameters. This shape allows for plasma shielding, if available at design stage, or magnetic shielding, if not. Such shielding need not be continuously operative since light bulk shielding should be sufficient 70% of the time. This design meets criteria for modularity and thus expansion, and also for standardization and therefore utilization of LEO station components.

Protection Against Meteoroids

Impacting meteoroids and drifting space junk pose a serious threat to the operational capability and security of long term missions and large space structures such as the GEO station. Unmanned spacecraft typically rely on

Meteoroid Danger



small size (lower impact probability) and system redundancy to elude fatal damage from space obstacles. However, persistent and unpredictable satellite failures, attributable to meteoroid impacts, clearly indicate that such approaches are unacceptable for large, manned space stations. Therefore, to ensure the long term survivability of a GEO station, it is imperative that meteoroid penetration into the station is minimized as much as possible.

The Geo station can utilize either active or passive approaches to reduce the risk of impacts. Active measures, considered for drifting space junk, consist of tracking and destroying incoming particles. However, such measures are neither realistic nor economically feasible for eliminating minute, high velocity meteoroids. Passive measures, which include reducing threatened surface areas and various forms of shielding, provide considerable protection against any type of projectile in the vicinity of the station. Of these, shielding is the only viable option for assuring reliable, long term protection of the GEO station.

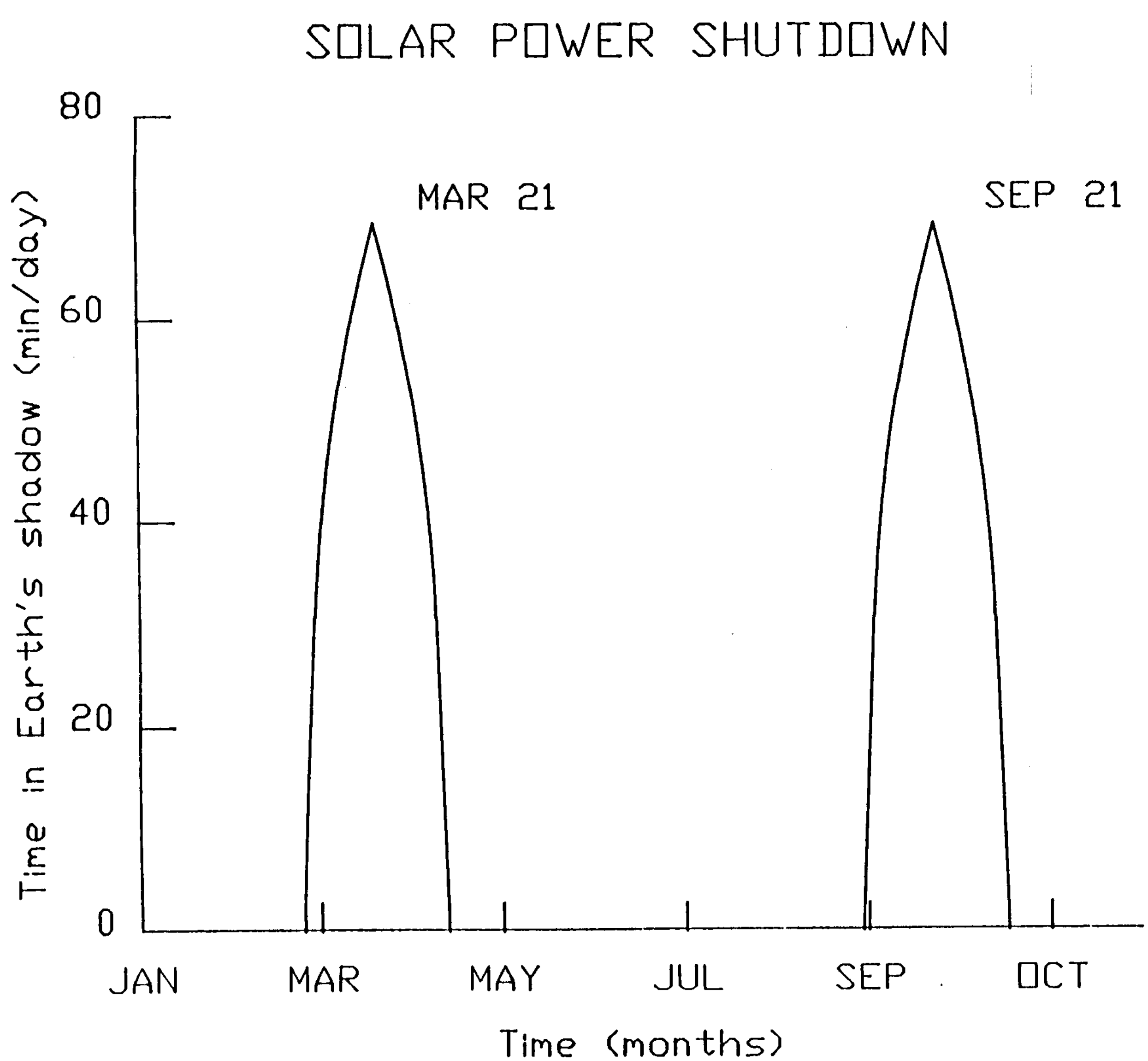
There are several different types of shielding available for use on a space station. Early manned missions employed thick walls as a shield against meteoroids, but this approach yields unreasonably heavy structures for large spacecraft. Excellent shielding with substantially less weight can be realized by double-wall structures which were used on Skylab and are intended for use on the European GIOTTO spacecraft. In double-wall shields, a thin bumper shield is used to vaporize the impacting meteoroid and a thicker backup shield (usually the wall of the spacecraft itself) takes the impact of the resulting vapor cloud. Since the vapor clouds spread proportional to the distance between the shields, the impact on the second shield is distributed and tends to bend the shield rather than penetrating it at a single point. Lightweight, but rigid materials make the additional weight of a double shield insignificant in comparison to the weight of the entire space station structure. One final advantage of the bumper shield is its simultaneous function as a radiation shield, thus limiting both heat loss to space and heat transfer to the cold superconductors of the plasma shielding.

Thermal Considerations

In GEO, maintaining a thermally stabilized and habitable environment, with average temperatures between 68-70o F, is no easy chore. To rotate the station in an attempt to simulate the thermal distributions found on earth would cause undesirable gravity gradients, stretch the complexity of the station to its limits and use costly power for maintenance. Furthermore, simple rotation will not even begin to solve the circulation and cooling problem that will exist in GEO station, for the sun is only an external source of heat. Many more sources emit heat from within GEO station. Therefore, an ammonia heat pipe circulation system will be used throughout the station.

During the spring and fall the station will move into the Earth's shadow and stay there a bit longer each day until at equinox the shadow will occult the station the longest: 69 minutes. During these dark periods no power may be pulled from the solar arrays and the fuel cells will operate at 50kw maximum. Insulation and other passive measures must be taken to ensure sufficient warmth at these times. GEO station will use 6 layers of Mylar insulation between the meteoroid bumper shields. It will also draw heat from the stored water, used as a thermal reservoir and heated during times when the Earth's shadow is not present.

The solar arrays provide 215 kw of power when in sun (which is 99% of any year), which eventually becomes waste heat. To cool the station and maintain an even temperature requires radiating this waste heat away. But the 1% of the time that the station is in shadow imposes the restriction that only 60 kw may be directly radiated from the station walls. One hundred and sixty square



SOLAR POWER SHUTDOWN
MAR 21
SEP 21
80
60
40
20
0
Time in Earth's shadow (min/day)
JAN
MAR
MAY
JUL
SEP
OCT
Time (months)

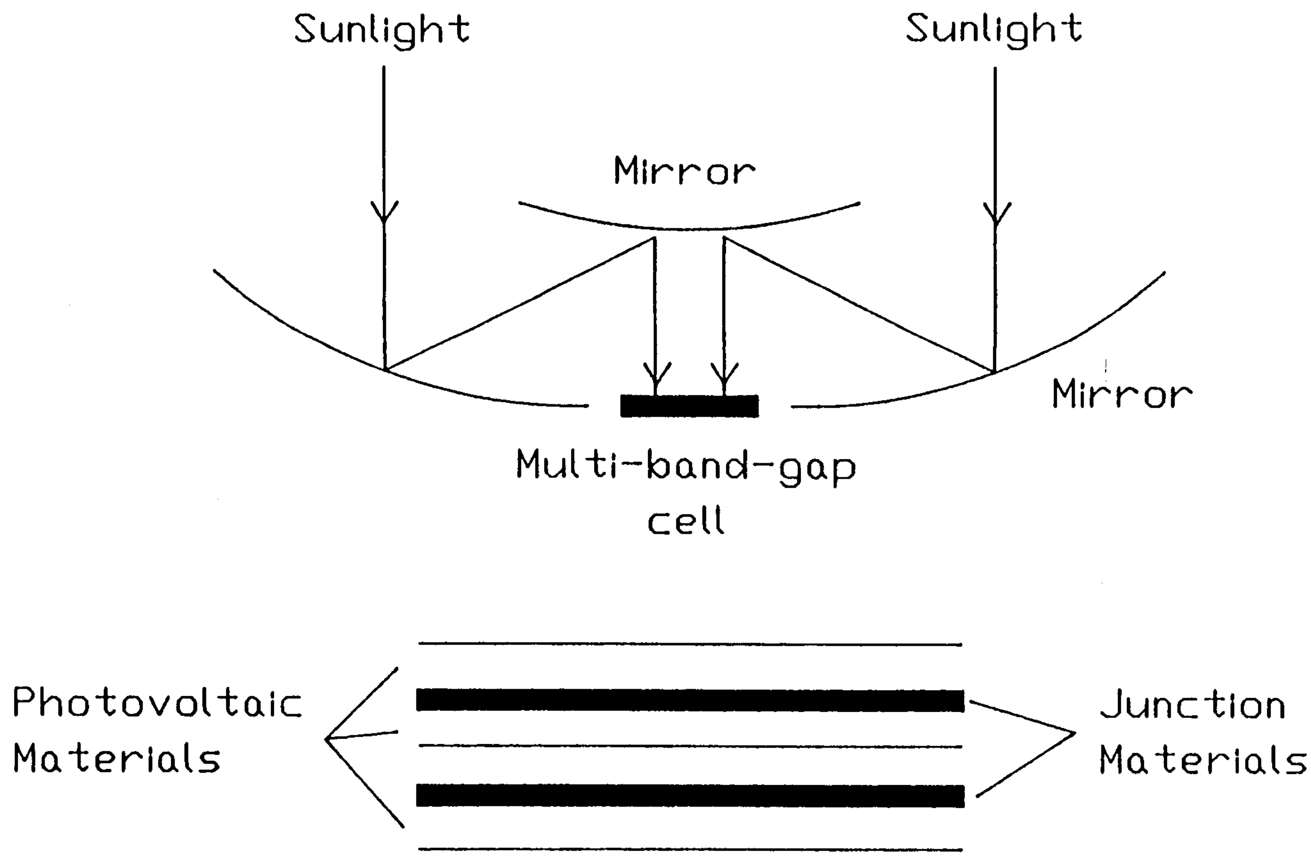
meters of radiators will be used to shed the remaining heat. The radiators will be placed on the support structure that anchors the solar arrays. Heat is pumped through them using the station circulation system. The radiators are shaped like chevrons (a heraldic symbol used on gas station signs) to provide meteoroid protection for the heat pipes which will radiate in space at 1 kw of heat per square meter. However, as previously mentioned, 99% of the time these radiators will be in the sun and will not radiate heat out. Furthermore, the station will be fully exposed to thee sun. Therefore, GEO station will have a parasol of approximately 2,000 square meters between it and the sun. This shade will consist of the solar arrays, the solar light collectors, and aluminum foil to fill in any gaps. It will allow the radiators to shed heat effectively and will keep the station within a predicted temperature circumstance; a far more manageable engineering situation.

Power

In order to provide energy to the various experimental laboratories, life support systems, shields, manufacturing facilities and ordinary daily amenities, GEO station must be able to provide large amounts of power at a relatively low cost. Many power sources exist to choose from: nuclear plants, solar arrays, solar dynamics, fuel cells, flywheels and batteries.

Nuclear power sources are light and relatively low in cost. They are not dependent on sunlight to produce power and can fit into a small volume. But, nuclear wastes are toxic and the plant must be heavily shielded. Special handling is necessary and reliability is low. For these latter reasons, nuclear power was not chosen for the GEO station. However, space exploration much beyond Mars cannot be accomplished effectively with short term or sun reliant power sources, and nuclear power for deep space travel must be

CASSEGRAINIAN SOLAR CONCENTRATOR



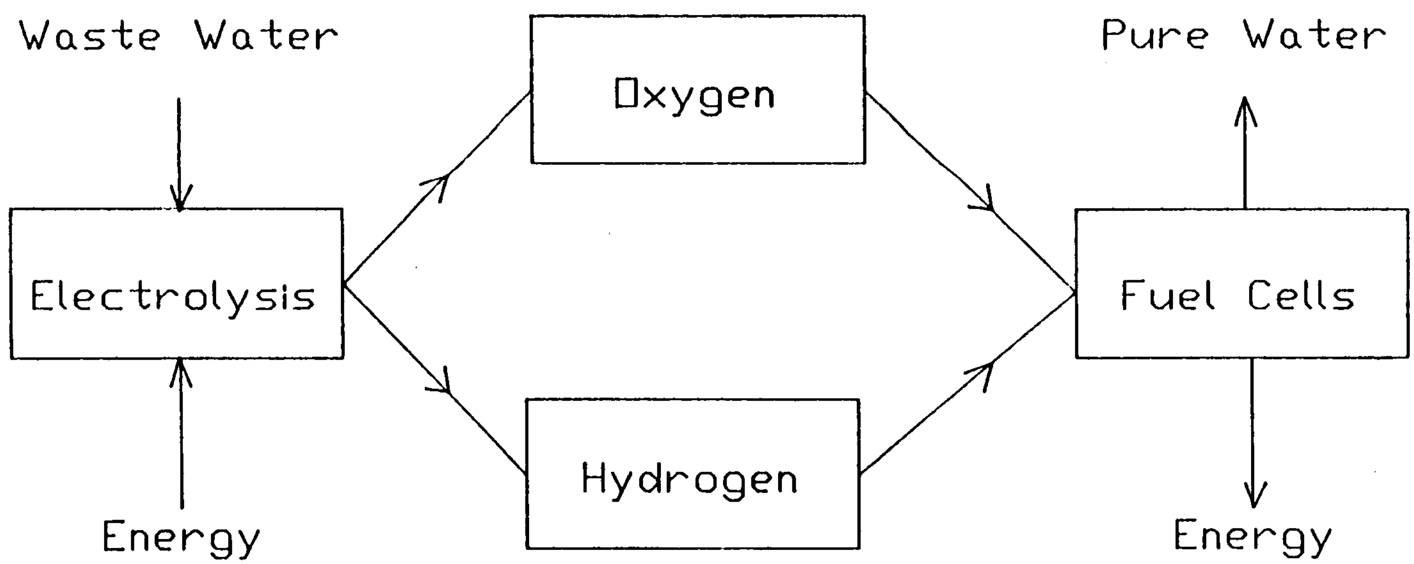
further explored as an eventual enabling technology.

The current developments in solar arrays makes them superior to solar dynamics. Sixty-eight percent efficiency is expected by the year 2000 using a miniature Cassigrainian concentrator concept with a multi-band-gap cell (see Figure PW-1). The sun's energy is concentrated, using a miniature Cassegranian mirror, onto a cell constructed of layers of photovoltaically active materials. Each material absorbs different wavelengths of light increasing system efficiency. To provide the 215 kw of power desired by the GEO station, a solar array parasol of 370 square meters will be used.

For one percent of each year a GEO station is in the Earth's shadow, minimal energy must still be provided during this time. The minimal power requirements to maintain the radiation shield and provide artificial access lighting are around 50 kw for short periods of time up to 69 minutes a day (as mentioned in Thermal Considerations). Of the lightweight, high powered options for power storage, the flywheel and the hydrogen/oxygen fuel cell were considered for their innovative technology and multipurpose designs. Because it is a characteristic of fuel cells to produce potable water as well as store power, hydrogen-oxygen fuel cells were chosen. To provide the 60km hr maximum energy necessary during darkness, five fuel cells will be used.

The amount of power needed for GEO station will be kept to a minimum by using the sun as a light source and using radiation shielding strategies that allow the plasma shield to be turned off some of the time. Artificial lighting is not required most of the time since light may be directly piped via optical fibers from the outside to the user with a Solar Light Collector system. More savings on power occurs due to the fact that the plasma shielding does not need to be on all the time, but merely for periods when radiation is intense.

FUEL CELLS AND WATER PURIFICATION



Plasmon cells are the newest power technology and will be added to GEO station in its growth period. Plasmon cells turn light into electricity with an efficiency of 80 to 90 percent. These super high yield, light weight power supplies will bring GEO station's available power levels high enough for profitable, ground based consumer use, or use in propulsion systems for exploratory craft. Free electron lasers based at GEO station could heat the fluids of a power plant on Earth or a propulsive gas on a spacecraft. The sun to consumer efficiency of the Plasmon-laser system is 72%. Such a prospect is limitless.

I. Introduction

A. Provide a safe habitation environment

1) protection against radiation
2) protection against meteoroids
3) provide adequate power
4) maintain comfortable environment

B. Provide excellent work environment

1) Facilities for satellite repair
2) Manufacturing facilities
3) Docking facilities
4) Free flyers for scientific applications
5) Communication facilities
6) Innovation opportunities

C. Design considerations

1) Modular design
   a) easy assembly in orbit via shuttle and OTV from LEO
   b) allows for future expansion and fabrication on-orbit
2) Flexibility of designs
   a) allow modification for different types of work
   b) allow for incorporation of new technologies
3) Use LEO designs to degree possible
   a) general structure of lab and habitation modules
   b) radiators
   c) docking facilities
4) Design station to be relatively autonomous
   a) reduce operational costs
   b) provide testing of technologies for long-term missions

II. Hardware Components for Safe Habitation Environment

A. Radiation

1) Radiation in GEO is dangerous
   a) Van Allen belt background radiation is high and has HZE particles
   b) Solar flare activity can produce particularly high levels of radiation
   c) Shielding is only practical means of protection
2) Bulk shielding
   a) Minimal wall structure of station will adequately shield environment 70% of the time
   b) Tremendous weight increase required to shield safety 100% of the time (for long missions and total exposure indices)
3) Plasma shielding
   a) superconductors in shape of torus would establish magnetic field
   b) electrons ejected from station form plasma cloud in magnetic field to provide effective shield
   c) advantages
      i) significant weight savings
      ii) shield can be turned on or off as needed
      iii) effective for other planetary radiation levels
   d) disadvantages
      i) EM communications through clouds are difficult (laser

communication works)
ii) plasma cloud forms high radiation area and danger for EVA's unless carefully controlled

B. Meteoroids
1) Meteoroids are dangerous in GEO
a) travel at high velocity (10-80 km/sec)
b) sporadic meteoroids have no preferred orbit inclination - meteor showers occur at inclinations less than 30^{o}
c) GEO station can expect impacts of particles 2 mm or greater each 15 years - smaller particles more frequently
2) Methods to reduce danger of impact
a) Reduce overall exposed surface area
b) Reduce area exposed in high risk directions
c) Provide emergency bulkheads between modules
d) Provide two independent accesses to each module
3) Shield to prevent meteoroid penetration
a) bumper shield design
i) outer thin wall (1.0 mm thick positioned 200 mm from station) vaporizes meteoroid upon penetration
ii) outer wall of station easily deflects diffuse meteoroid vapor
b) shield to be made of Kevlar
i) high shock compressibility to insure vaporization
ii) less bumper erosion (i.e., smaller holes are produced in material and holes are easily repaired)
iii) rigidity allows ease of attachment of shield to station
4) Additional measures
a) provide thicker or additional shields in high risk directions
b) provide passive shield or "bunker" area for emergencies

C. Power
1) Energy requirements
a) 50 Kw minimum maintenance power required
i) 40 Kw for plasma shield
ii) 10 Kw to sustain station
b) 200-250 Kw during peak usage (full usage)
i) 40 Kw for plasma shield
ii) 50 Kw for CELSS
iii) 110-160 Kw for operations
2) Solar arrays design
a) suggest Cassegrainian concentrators with multi-band-gap cascaded cells
i) anticipate 750 w/m^2
ii) require 300 m^2 to satisfy needs
b) locate along toroidal axis outside area of concentrated plasma
c) use to shade station from sun
i) shape in form of hollow octagon
ii) shading one module requires 84 m^2
- only four modules shaded by required array
- use alufoil to shade additional modules
d) plasmon cells should be evaluated and developed for future use
3) Fuel cells (50 Kw)
a) Provides energy when solar arrays are inoperable
i) during slowdown phases
ii) if solar arrays fail

b) provides pure water for drinking, cooking etc.
   i) must operate 90 min/day to produce 25 kg of H_2O
c) Recommend storing 200-300 Kg each of H_2 and O_2
   i) can supply energy during emergencies
   ii) easily supplies enough energy during slowdown phase

D. Thermal Hardware
  1. Considerations
    a) if uncontrolled, station will heat excessively during sun phase
    b) station will cool excessively during slowdown phase
    c) active measures required to accommodate range of heat transfer (heat pump)
  2. Design to handle slowdown phase
    a) passive methods
      i) meteoroid shield will help prevent radiative loss
      ii) mylar insulation will further reduce heat loss
    b) active methods
      i) use heat produced by fuel cells and distribute through station
      ii) heat station to maximum prior to slowdown phase
      iii) store heat in station water prior to slowdown phase
  3. Design to handle sun phase
    a) passive methods
      i) use solar arrays and alufoil to shade station
    b) active methods
      i) use heat radiators to dump heat into space
        - heat transport to radiators pumped through heat pipes at high temperature gradients
        - use improved Chevron fin radiators from LEO
        - require 160 m^2 at 1 Kw/m^2
        - Chevron fins protect heat pipes from meteoroids
      ii) buffer short-term excess heat production by heating station storage water

III. Hardware Components for Work Environment
  A. Satellite repair shop
    1) Pressurized module with direct access to hangar via air lock
    2) Capable of repairing electrical and mechanical satellite components
      a) well equipped with tools
      b) computerized machine capabilities
      c) tools and processes for producing electronic components including integrated circuits (VLSI)
    3) Computer workstation with communication to Earth to allow programming of machine tools
    4) Located outside region protected by plasma shields
      a) not readily accessible during times of high radiation (25% of total time)
      b) might use special suits to access area even during high radiation

  B. Hangar
    1) Nonpressurized but safe working area during normal background radiation
      a) large hatch at one end
      b) storage area for retrieved satellites and free flyers
      c) starting point for extra vehicular activity
    2) Made from spent liquid hydrogen tank of shuttle

a) attached to docking tunnel outside region protected by plasma shield
b) repair shop module located at one end

C. Storage bay
1) Nonpressurized large storage
a) water
b) gases including H_2 and O_2 for fuel cells
c) liquid coolant for plasma shield superconductors
d) extra foodstuffs
e) raw materials for manufacturing (debris, old satellite components)
f) spare parts, etc.
2) Made from spent shuttle tank attached to docking tunnel

D. Free flyers
1) Communications antenna
a) plasma shield provides barrier to direct electromagnetic communication
b) free flyer substation communicates with Earth and other satellites normally and with GEO station via laser beam
2) Scientific free flyers
a) observatories
i) long periods of unobstructed views
ii) no atmosphere to disturb measurements
b) large synthetic aperture produced from two widely spaced satellites
3) Other free flyers
a) gravity module (discussed in habitation section)
b) phased array radar satellites (discussed in meteoroid protection section)
c) robots and satellite retrieval systems

IV. GEO Station Living Areas
A. Modular design
1) Use modular approach applied in LEO
2) Four modules provided initially
a) house living quarters
b) central control area
c) CELSS components
d) exercise facilities
e) leisure and recreation facilities
f) labs and work areas
3) Expansion within torus to easily include eight modules - layered second torus would allow further expansion

B. Internal design to emphasize physical and emotional comfort
1) adequate space
2) sound proofing
3) flexibility in arranging personal quarters
4) color, lighting, temperature, etc.
5) communications with Earth systems

NOTES:

If Clean Drinking Water is a Driver:

there must be 25 kg water/day so therefore the fuel cells must discharge 90 mins a day, they must also charge 153 mins a day. (50% off in charge)

Plus:

The station is in the shadow of the earth for apx 3826.66 minutes/yr

For:

A grand total of 365 x 153 + 3826.66 = time on batteries/yr.

59671.66 min/yr = 11.3% of the time

During this time:

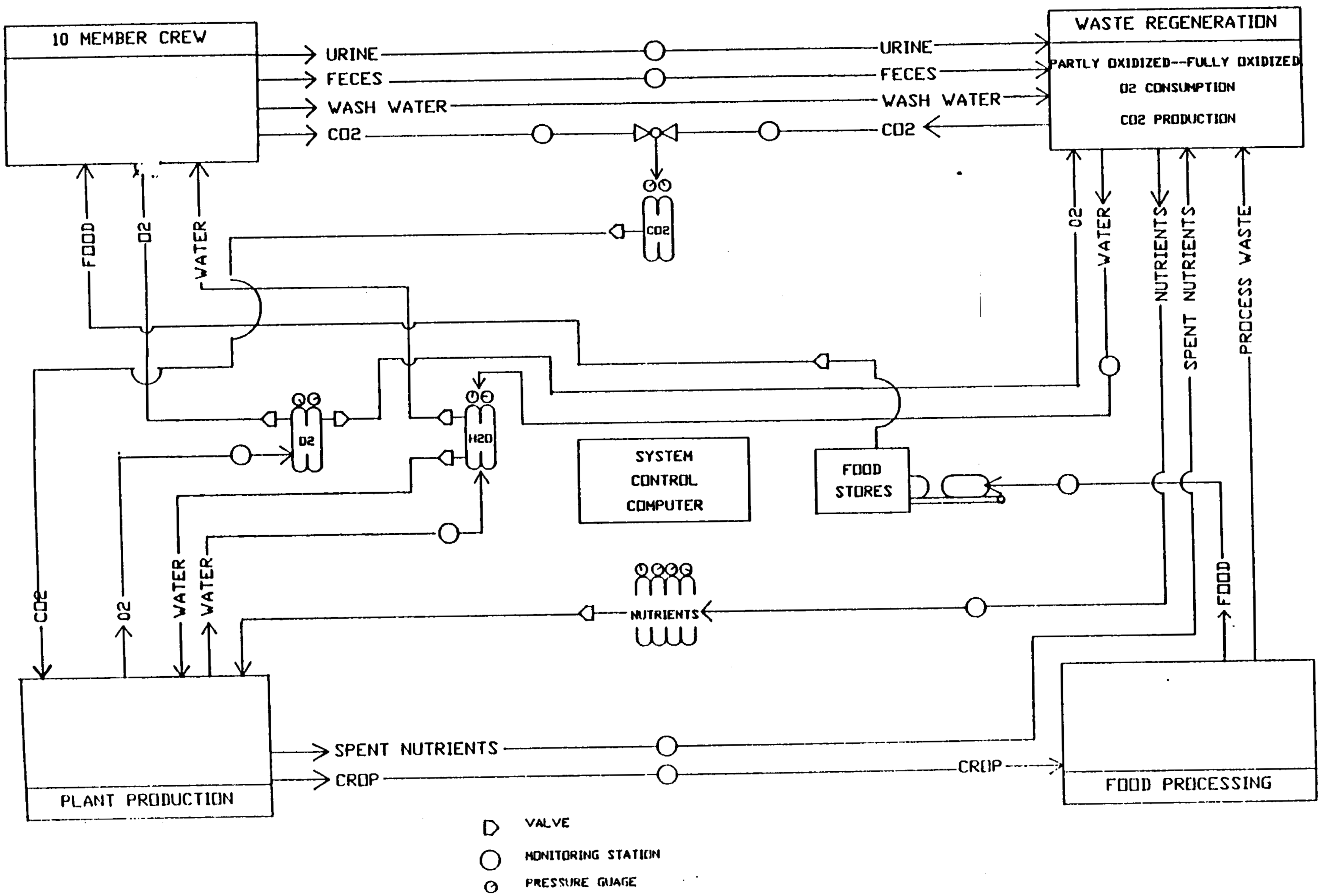
Station pwr reqs are 50 kw 30% of the pwr which is otherwise provided. Batteries operate at 50% efficiency so 11% need 1/3 of twice the normal operating power, or 7.5% of all power must be diverted from arrays to batteries. Or, array size must increase by apx 7.5%.

CELSS

There are several important factors to consider when designing life support systems for the GEO station. First and foremost, the feasibility of deep space exploratory spacecraft or lunar and planetary bases hinges on the successful demonstration of an autonomous space station ecosystem. The GEO station would provide an unprecedented opportunity for the design, development and testing of a full scale "mock-up" of a Controlled Ecological Life Support System (CELSS) in a microgravity environment. Second, the operational realm of the GEO station, compared to LEO station is unique; the radiation environment is severe, partly due to the prevalence of high charge and energy (HZE) particles, and the station remoteness is extreme. Establishing the highest degree of station independence possible, through the use of a CELSS, would help maintain a comfortable and secure atmosphere for crew members. Further, proving that a CELSS could thrive under such harsh environmental conditions would be a significant stepping stone for future deep space missions. Finally, the economic considerations of a CELSS are not without merit. Once established, a CELSS maintains a constant mass balance throughout the station; food, water and atmosphere are continuously regenerated. In contrast, sustaining a crew by resupply requires exorbitant station storage capabilities and exceedingly high payload costs due to the replenishment of heavy materials such as water. Thus, although not absolutely essential for the success of a GEO station, a CELSS would be a logical next step in the ongoing development of innovative technologies for a manned presence in space.

What are the materials which need to be considered for recycling in a CELSS? Idealistically, everything in the GEO station must be considered a candidate for recycling. In practice, however, solids, liquids and gases

SCHEMATIC DIAGRAM OF CELSS CONTROL SYSTEM



generated by crew members and other biological organisms will comprise the bulk of materials in a CELSS loop. Regenerating such materials into usable forms is not trivial; phase separation and fluids management, for example, pose intricate processing questions. Assuming such processing problems can be overcome, there will continue to be other crucial issues inherent to a GEO CELSS which must be addressed. How can the depletion of essential nutrients from the system be minimized? How can the accumulation of toxins or the conversion of substances into nonusable forms be avoided? Current approaches to these issues typically involve the introduction of "cheating vectors" into a CELSS. Obviously, however, heavy reliance on cheating vectors themselves will ultimately defeat the system. What, then, can be done to preserve the long term viability of a CELSS? Delving into the agricultural domain, a proven approach to these not so unique issues is apparent; the method of "crop rotation". This procedure involves the use of different plant species (alfalfa, clover, legumes and nuts are common in agriculture) to replenish fixed nitrogen supply, revitalize growth media and eliminate parasitic contamination. In stark contrast to the disrupting external manipulations of cheating vectors, a crop rotation scheme can be readily incorporated into the constant mass balance of a CELSS. Such a scheme needn't stop at simply maintaining status quo however. An appropriate selection of micoorganisms and higher plants for rotation within a GEO CELSS could lead to enriched nutrient supply, enhanced crop productivity and a wide variety of nourishing crops for the inhabitants of the station.

Success of a GEO CELSS is further contingent upon the shrewd design of its various hardware components. The closed nature of the system mandates an efficient, conservative use of available materials. The aeroponic method of growing higher plants was therefore discarded in favor of hydroponics due to the grossly inefficient manner in which nutrient solution is delivered to

CANDIDATE MICROORGANISMS AND HIGHER PLANTS FOR CELSS

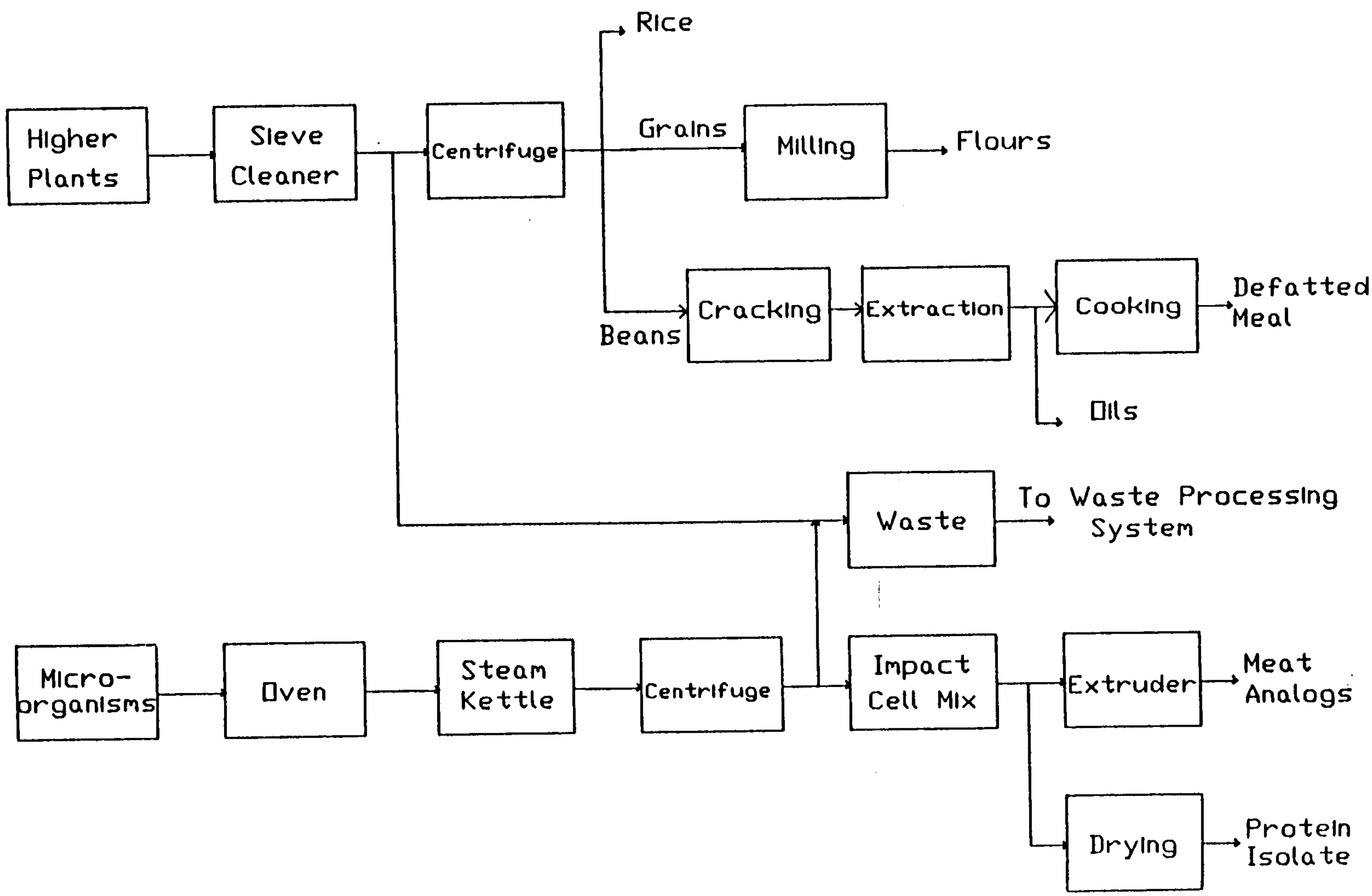
MICROORGANISMS	COMPATIBILITY WITH CROP ROTATION SCHEME	SATISFY NEEDS OF CREW: OXYGEN	SATISFY NEEDS OF CREW: 'NUTRIENTS'	GROWTH SUITABILITY FOR CELSS	STORAGE CAPABILITY	PALATABLE FOOD SOURCE
CHLORELLA	---	YES	PROTEIN	GOOD	GOOD	COULD BE
ANABAENA	YES-N2 FIXATION	YES	PROTEIN	GOOD	GOOD	COULD BE
CANDIDA	---	---	VIT. B	GOOD	GOOD	YES, AS ADDITIVE
SACCHAROMYCES	---	---	VIT. B	GOOD	GOOD	YES, AS ADDITIVE
BASIDIOMYCETES	---	---	NICOTINIC & RIBOFLAVIN	GOOD GROWS ON SLUDGE	GOOD	YES COMMON MUSHROOM
NITROBACTERACEAE	YES-N2 FIXATION	---	PROTEIN	GOOD GROWS ON SLUDGE	GOOD	---
<u>HIGHER PLANTS</u>						
SOYBEANS	YES	YES	PROTEIN	GOOD-GROWS WELL IN POOR GROWTH MEDIA	GOOD	YES
POTATOES	---	YES	CARBO	GOOD	GOOD	YES
BROWN RICE	---	YES	CARBO	GOOD GROWS IN LIQUID	GOOD	YES
PEA POD	YES	YES	CARBO	GOOD-GROWS IN ARTIFICIAL LIGHT	O.K.	YES
SPLIT PEA	YES	YES	PROTEIN, CARBO, ZN	GOOD-GROWS IN ARTIFICIAL LIGHT	GOOD	YES
KALE	---	YES	CALCIUM	O.K.	POOR	YES
BROCCOLI	---	YES	VIT. B	O.K.	POOR	YES
TOMATO	---	YES	VIT. C	GOOD-STRONG ROOT SYSTEM	O.K.	YES
DRY BEANS	---	YES	PROTEIN, CARBO	O.K.	GOOD	YES
CABBAGE	---	YES	CARBO	O.K.	O.K.	YES
STRAWBERRY	---	YES	VIT. C	GOOD-HEARTY	POOR	YES
ONIONS	---	YES	FLAVORING	GOOD	GOOD	YES, AS ADDITIVE
GARLIC	---	YES	FLAVORING	GOOD	GOOD	YES, AS ADDITIVE

roots. Similarly, the considerable weight of soil (payload considerations) and its innertness or inability to be used elsewhere in the system makes soil prohibitive as a growth medium. Overlapping station systems or CELSS system components is an excellent strategy for using materials efficiently and conservatively. For example, fuel cells were chosen as a backup power source for the GEO station not only because of their reliability but also because of the ability of the cells to produce highly purified water. In the waste treatment process, microorganisms used as catalysts in the biological breakdown of wastes were chosen based on applicability to the crop rotation scheme (bacteria which fix nitrogen) and potential use as a food source (the fungus Agaricus bisporus is the common mushroom). One final design criteria for the CELSS hardware is simplicity; the system should be "user-friendly". Automation and smart robotics will be integrated as much as possible into CELSS in order to alleviate the burden of tedious system maintainence from crew members.

Food Processing

Spending a relatively long (6 months) period of time in a closed, microgravity environment far from home will obviously place many stresses upon the crew of the space station. Simple pleasures could make all the difference between having a happy, productive crew, or a bunch of astronauts counting the hours until they return to solid ground. One of the basic pleasures of life is eating. Another, for some people, is preparing a special meal. On GEO we will grow both unicellar and some higher crops (soybeans, rice, greens). Some of these products of the CELSS system, though very nutritious, are not readily accepted foods. The food served to the crew should look and smell appetizing, have a normal texture, and be varied from day to day. Therefore, designing an efficient food processing system for the space station now,

FOOD PROCESSING SYSTEM



and for space travel in the future, is a necessity.

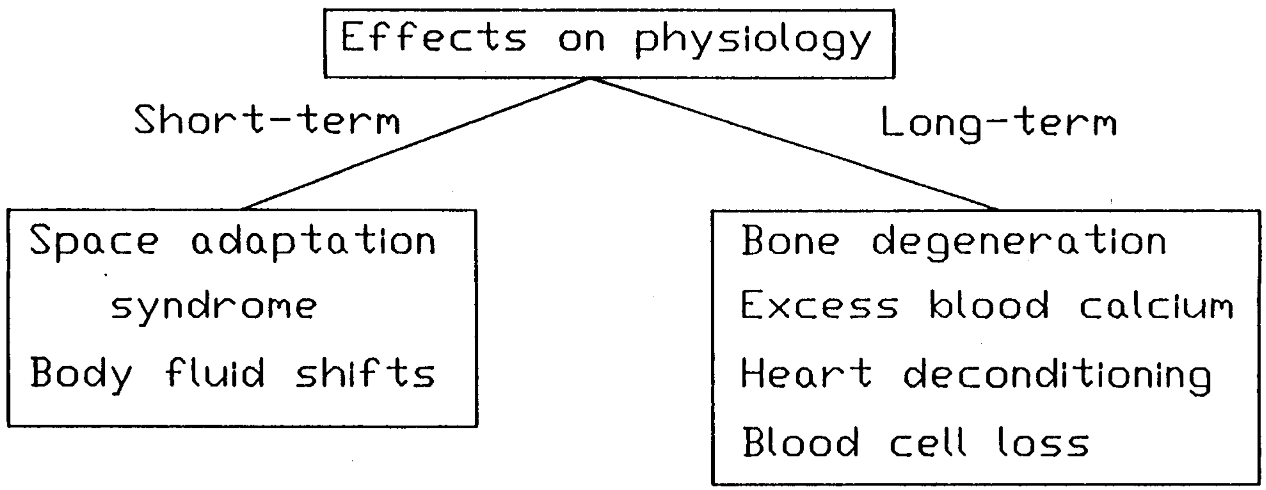
The system should have the capability of handling a variety of higher plants as well as single cell protein sources (algae, yeast, bacteria, fungus). Simplicity and lightweight are essential assets, with noise and other types of environmental pollution held to a minimum. It should be possible, using robotics, to design a fully automated system which has connections to the plant harvesting units and waste processing system. Crew members could then use this system to create their own specialty dishes. Simply from soybeans and single cell protein sources, for example, several different types of food can be produced. Using different flavorings and food colors, meat analogs can be made which look, taste and smell like chicken, turkey, or even shrimp. Soy flour could be used to make breads, pasta, etc. and oil can be extracted from the beans to be used in food preparation. These foods, along with the other vegetables and fruits grown in the space station, could make for some interesting meals.

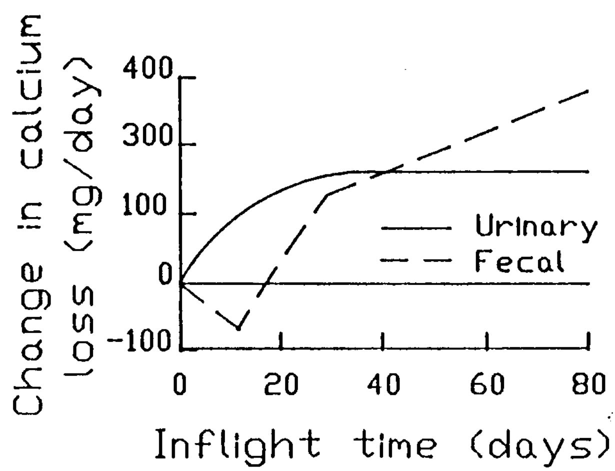
Biomedical Aspects of GEO Space Station

A geosynchronous space station would represent a large step in moving from an era of space exploration to an era of space exploitation. As such, the people who live and work at the station most likely will not be the rugged astronauts of the past but rather physically ordinary individuals who possess special skills in communications, satellite repair or scientific research. Health considerations must evolve to ensure more than just survival of the space station inhabitants; good health along with physical and psychological comfort must be emphasized.

Ensuring good health in the geosynchronous station represents a challenge because of large amounts of radiation, the degenerative effects of microgravity, isolation for long periods of time at relatively large distances

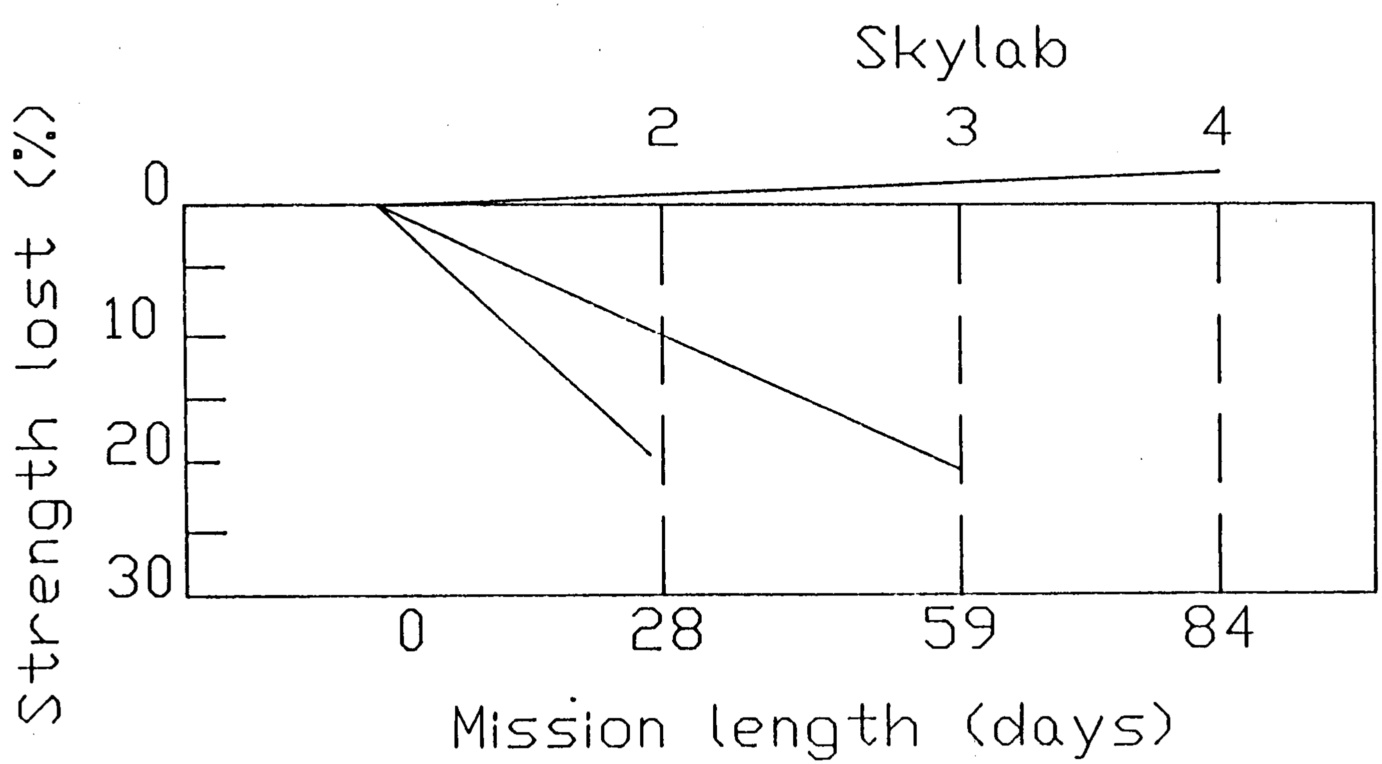
MICROGRAVITY CONCERNS





Redrawn from Dietlein and Johnston, 1981.

BENEFITS OF EXERCISE



Redrawn from Thornton and Rummel, 1977.

RADIATION CONCERNS

Radiation at GEO vs. LEO

Orbit	Dose (rads) from Background	Dose (rads) from Solar flares	Total
LEO	32	---	32
GEO	300	250	550

Effects on health

ACUTE

Dose (rads)	Symptoms
50-200	vomiting, fatigue
200-550	vomiting, fever, hemorrhage, disability, 50% deaths
550-up	severe radiation sickness, almost 100% deaths

CHRONIC

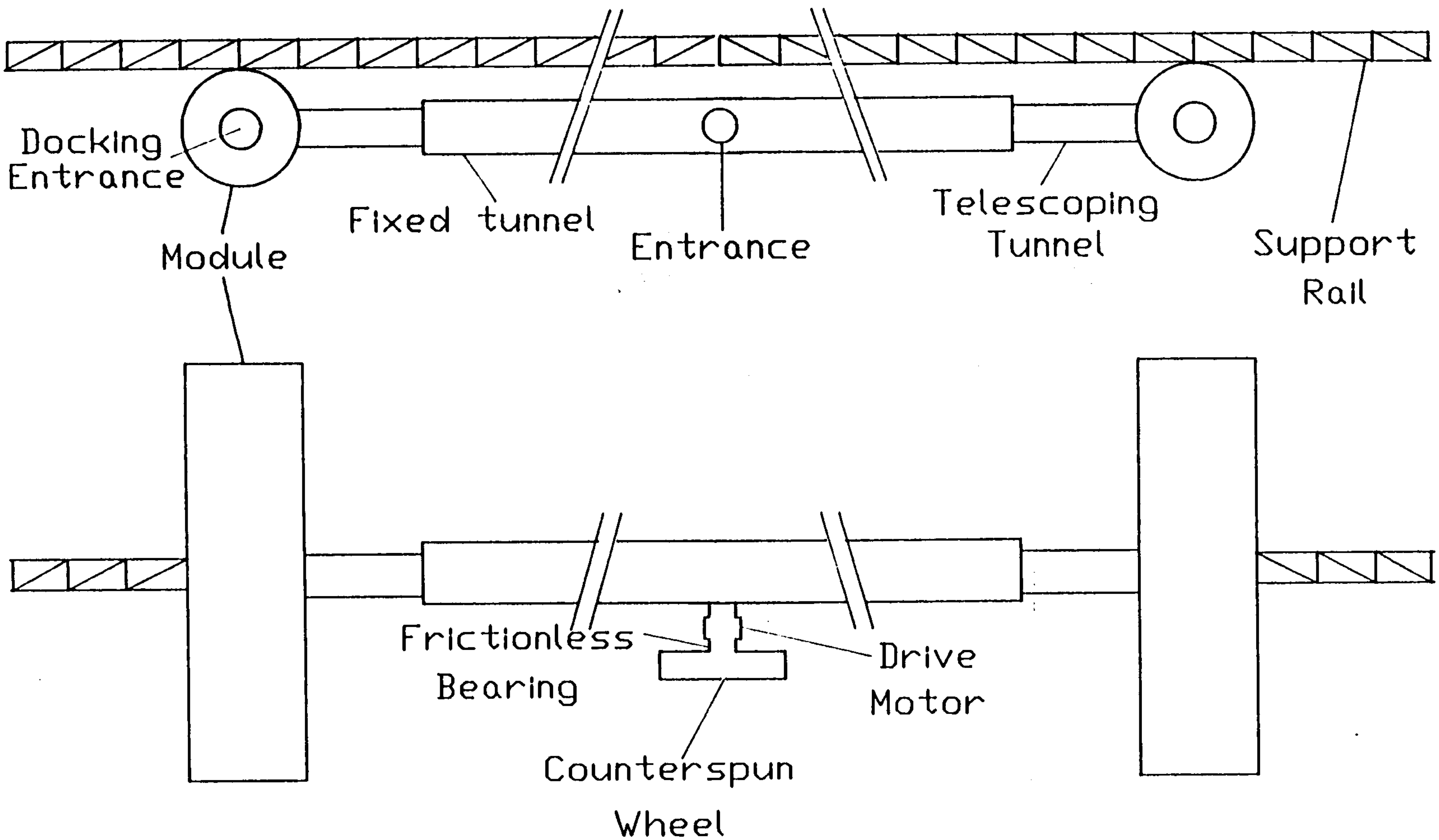
Increased risk for
- -cancer
- -reproductive problems

Risk increases with dose

from Earth and potential difficulties of a CELSS. Radiation shields have been designed to ensure protection even during episodes of large solar flare activity. Health monitoring will be emphasized to allow early detection and treatment of any health problems. Such monitoring will be set up to obtain detailed information while disturbing the astronauts as little as possible. Capabilities for emergency medicine will allow for the handling of virtually any crisis.

One way to solve microgravity related problems is to provide artificial gravity by spinning the station. To spin the whole station, however, would be structurally difficult and would defeat the advantages of manipulating satellites and other large structures in microgravity. In addition, data do not currently exist to allow optimization of spin radius and velocity. As a complement to the main station, a gravity module has been designed. This module will provide a stie for health maintenance, emergency medicine, interactions with CELSS, research and gravity readaptation and quarantine. The gravity module has been designed with variable spin radius and angular velocity so that optimal parameters can be determined. By having gravitational and microgravity environments side by side, research can be done to determine the desirability of using artificial gravity for deep space missions.

GRAVITY MODULE



I. Introduction
    A. Living and working in a geosynchronous station
        1. Initial crew of 10 people
        2. overlapping expertise of crew members
        3. emphasis on habitation rather than simply surviving
    B. Activities in GEO
        1. work related activities (9-10 hours/day)
            a. satellites and communications
                i. GEO orbit is clogged with useless satellites and debris
                ii. station would retrieve and repair satellites -- correct faulty orbits; upgrade satellites; clean orbit
                iii. GEO station can serve as a base for construction, operation and repair of a GEO based antennae form
            b. science based activities
                i. space based investigation
                    - geophysical
                    - astrophysical
                    - astronomy
                    - life sciences
                ii. applied space based investigations
                    - materials
                    - solar cell technology
                    - engineering R&D
            c. materials manufacturing and processing
                i. on board capability to manufacture materials for satellite repair and refitting
                ii. lunar materials easily accessible for manufacturing needs
            d. surveillance/military
                i. monitoring of Earth's surface, atmosphere and communications
        2. "Living" related activities (14-15 hours)
            a. eating/food preparation
            b. health maintenance and support
                i. exercise
                ii. monitoring
            c. station maintenance and support
                i. robotics should minimize crew intervention in basic maintenance
            d. leisure time/sleeping

II. Controlled Ecological Life Support System (CELSS)
    A. Introduction
        1. What is a CELSS?
            a. A controlled ecological life support system is a system which contains all the processes necessary for transforming waste materials into energy enriched foods, and back into waste material.
            b. Both endogenous biological processes and human engineered processes are required.
            c. Although energy may flow freely through the system, mass flow in and out should be reduced as much as possible.

2. Why have a CELSS?
   a. Because of the high altitude (22,236 miles) of a GSO, resupply is costly. It has been estimated that for a 10 member crew in GSO, CELSS becomes cost effective for tours of 3 months and longer. Since we are considering 6 month periods between crew changes and resupply, a CELSS becomes cost effective.
   b. A GSO space station would be a logical place to develop and refine CELSS technology. Such technology will be necessary for long term manned missions into the solar system, as well as for manned bases on planets, moons, asteroids, etc.
   c. CELSS technology will further our understanding of ecosystem dynamics. This will be important for earth based problems ranging from the preservation of existing ecosystems to providing for the food and waste disposal needs of a large (growing?) world population.

B. CELSS considerations/difficulties
1. Materials which need to be considered for recycling in CELSS
   a. solids such as feces, inedible biomass, food processing wastes and uneaten foods
   b. liquids such as urine, spent nutrient solutions and spent wash water
   c. gases such as oxygen from plants, carbon dioxide from crew, excess heat and water vapor
2. Materials which require special consideration
   a. Toxins
      i. one of the primary difficulties in a CELSS is the production of substances toxic to people and/or plants. For example, some algae give off toxic gases such as HCN, NO compounds and volatile amines or ammonia. Although such substances are generally released in minute quantities, in a closed loop system toxic levels are eventually reached.
   b. Nonusable forms of compounds
      ii. another difficulty with CELSS is the conversion of elements into molecular forms (i.e. ash, nitrogen, various salts, etc.) that, while not necessarily toxic, cannot be easily reclaimed by the system. Even if conversions are small and slow, in a cycling system large amounts of mass will eventually end up in nonusable forms and the system will fail.
3. Control problems
   a. In reducing a bioregenerative system down to only a few processes, much of the normal buffering capacity is lost and systems often fail because of process control difficulties.

C. Approaches to CELSS
1. Agricultural approaches
   a. crop rotation
      i. in soil growth media, succesive generations of crops tend to leach nitrogen (nitrites) from soil
      ii. a "crop rotation" scheme is commonly used in agriculture to replenish nitrite supply and revitalize soil
      iii. using crop rotation in a CELSS could similarly maintain the viability of the system by preventing the depletion of important nutrients

iv. more importantly, crop rotation in a CELSS could serve to enrich nutrient supply and thus enhance crop productivity

b. crop selection/criteria

i. there are several different considerations which dictate the selection of CELSS "crops" :

ii. compatibility with crop rotation scheme

- certain types of plants are commonly used in agriculture for crop rotation : alfalfa, clover, legumes and nuts
- microorganisms could also play an important role in maintaining CELSS viability : some blue-green algae fix nitrogen; many species of bacteria fix nitrogen

iii. "nutrient" requirements of crew - this includes adequate production of oxygen as well as food supply

- many microorganisms have a high protein content : algae (all types) average 50% protein while fungi typically contain approximately 40% protein
- higher plants such as soybeans and split peas are also high in protein although not as high as microorganisms
- crops (microorganisms and higher plants) will produce approximately 25 l/m^2/day of oxygen and assimilate 23.8 l/m^2/day of carbon dioxide

iv. growth considerations

- algae require special harvesting equipment to separate biomass from nutrient solution
- higher plants can not have extensive, complex root systems or fragil constitutions - growing peanuts and corn would be eliminated (mostly based on root structure); also wheat poses many processing problems
- crops should be hearty and not extremely sensitive to changes in nutrient solution or lighting (should be able to survive with artificial light) - clovers are typically vigorous growers with crop rotation overlap

v. storage capability

- it is absolutely crucial that crops can be stored for long term use
- algae and fungi can be stored in a spore stage for more than a year; matured algae can be freeze-dried
- higher plants such as soybeans, rice, potatoes, peas and beans can be stored once processed - all plants can be stored initially as seeds

vi. palatability

- it is likely that crew morale would suffer on a diet of unidentifiable green mush - food variety is an important consideration
- spices and other flavoring crops such as onions and garlic should be included in a CELSS
- the fungus Basidiomycetes (common mushroom) can be grown in adverse conditions (waste management overlap) and would also provide flavoring
- "interesting" crops with limited storage capability could be included : tomatoes, cabbage, broccoli and

strawberries
- white clover, used for crop rotation, could also be exposed to a special GEO bee population for honey production

2. Waste management approaches
   a. wet oxidation
      i. solids (or large organic molecules) can be decomposed using high temperatures and pressures typical of wet oxidation
      ii. pathogens are destoyed in extreme temperature and pressure conditions somewhat too oxygen intensive for regular use (purification)
   b. electrolysis
      i. purification of spent nutrient liquids
   c. activated sludge system
      i. microorganisms are typically used as catalysts in the biological breakdown process (bacteria, yeasts, fungi and protozoa)
      ii. many bacteria species (i.e. polymyxa, N. winogradskyi) potentially useful to activated sludge system fix nitrogen
      iii. fungus such as Agaricus bisporus (common mushroom) can be grown on sludge (and used as a catalyst) and provide a food source

D. Hardware components of CELSS
1. Algae growth chambers
   a. These chambers will be spun at low angular velocity during growth phases in order to remove metabolic by products and to introduce nutrients. Higher spin rates will be used to harvest algae solution into gas, liquid and solid phases.
   b. Although the number and size of chambers have not been decided on, approximately 15 kg of algae must be held under adequate lighting and nutrient conditions in order to provide enough food and oxygen for the crew. This is in the absence of higher plants.
2. Higher plant growth chambers
   a. In the absence of the algae system, a higher plant growing area of approximately 165 m^2 is needed to provide crew with nutrients. 10 separate growing chambers of approximately $17m^2$ each could then be envisioned. At 150 watts/m^2, the total power requirement would be approximately 25 kW. This area of plants, however, would only produce approximately 6 kg of the approximately 7 kg of oxygen needed by the 10 member crew.
3. Food processing
   a. General requirements
      i. keeping processing equipment simple and light weight while maintaining versatility
      ii. finding, or constructing, reliable equipment that requires a minimum amount of maintenance and provides maximum automation
      iii. keeping noise and chemical pollution to a minimum and safe level
   b. Processing of soybeans, SCP and rice
      i. soybeans - products :
         - soy flours, grits

- protein isolate
- tofu

ii. soybeans - processes :
   - the steps in the production of soy flours and grits include cleaning, drying, dehulling, cracking, flaking and cooking
   - to produce textured soy protein, soy flour is mixed with water (and flovoring, colors, nutrients, etc.) and then passed through a cooker-extruder
   - to isolate soybean protein, flakes are extracted in tanks containing water or mild alkeline solution. Extract is then acidified to precipitate protein into a curd, which is neutralized with NaOH and spray dried.
   - to make tofu, beans are washed and then blenderized with boiling water for a short time. The mixture is steamed for 30 minutes and then filtered through muslin bags producing soy milk. The curd is precipitated by adding 0.2% $CaSO_4$, placed in hoops and pressed overnight at 1 psi.

iii. Single cell protein - products :
   - scp from algae and bacteria is best used to produce meat analogs which can be flavored to taste like turkey, beef, shrimp, etc.

iv. Single cell protein processes :
   - fermentation of cell culture, possibly using food wastes as a substrate
   - heat shocking to kill cells, which are then cooled and incubated for a couple of hours
   - separation, by centrifugation, of cells from waste. Cells are then washed
   - disintegration of cell walls using impact-cell mill. The scp is then either concentrated, dried and packaged or further processed
   - nucleic acid removal, using endogenous RNase
   - the protein water mixture is extruded using one or possibly two extruders. Volatile flavor precursors and water vapor are flashed off during this step. A dense, meat-like product emerges

v. Rice - products :
   - brown rice, with bran layer intact
   - white rice, with bran layer removed, would require more equipment and be less nutritious and therefore not worth producing

vi. Rice - processes :
   - cleaning
   - rice is passed through a sheller to remove hulls
   - fanning maching removes dust and husks
   - the rice is usually passed back through the sheller to make sure all hulls are removed

c. Use of by products

i. waste materials - some wastes, such as those produced in soybean processing, contain sugars and other substances which could be recycled and used, for example, as a substrate for growing bacteria

ii. heat - heat is produced at several points in the processing and, if a suitable means of entrapment is found, could be stored in some manner or used to produce electricity - could be timed to coincide with station shadowing

d. Energy requirements

i. a very rough estimate is 1-2 kW needed for food processing

4. Storage Tanks

a. raw gas, liquid, biomass, seed and spore storage

b. enriched or purified gases, liquids and processed foods

5. Waste disposal units

a. crew waste collector - probably want at least 2 for 10 person crew

b. wet oxidation system

i. requires high temperatures and pressures to operate

ii. existing unit size capacity 27.9 kg - at least 2 would be required with a total power usage of 570 W

c. activated sludge system

i. reactive tanks would have to be designed for microgravity environments

ii. microorganism species should be chosen so as to be useful for other parts of CELSS (i.e. bacteria which would fix nitrogen)

iii. energy requirements of system would be minimal

iv. system has slow turnover time and does not adequately decompose certain organic molecules - system would have to be coupled to another waste treatment process such as wet oxidation

6. Other purification and monitoring hardware

a. Gas separation units

i. CO_2 removal - 1047 W power required

ii. CO_2 reduction - 190 W power required

iii. catalytic oxidizer - 572 W power required

iv. may store enriched rather than pure gases

b. Water purification unit

i. electrolysis system - approximately 53 kW power required

c. monitors

i. water quality monitor - 40 W power required

ii. atmosphere monitor - 300 W power required

d. miscellaneous

i. dehumidifier

ii. odor control via activated charcoal filtration (available from oxidation)

III. Biomedical Aspects of GEO

A. Introduction

1. Effects of GEO environment on health

a. Radiation

i. Radiation exposure can cause many health problems depending on dose received

- acute effects of large doses are well known
- chronic effects of lower doses include increased risk for cancer and reproductive problems

ii. Radiation in GEO far exceeds current acceptable levels for radiation exposure (Table)

iii. Adequate shielding from radiation is only known means for prevention problems

iv. HZE particles deserve special attention
   - HZE particles are unique to space environment at GSO
   - little research has been done on this type of radiation (i.e., health effects of HZE particles are unknown)
   - particles are much larger and more energetic than other forms of particle radiation (it might not be possible to extrapolateeffects of HZE particles from effects of other radiation types)
   - due to nature of particles, shielding is difficult

b. Microgravity

i. Many physiological changes result upon entering a microgravity environment which can be grouped into various categories
   - adaptation responses that appear to have no health consequences (e.g., fluid shifts, blood cell loss, etc.)
   - Changes that cause health difficulties but are temporary (e.g., space adaptation syndrome)
   - Changes that could cause problems and are not temporary (e.g., musculoskeletal degeneration, cardiovascular deconditioning, etc.)

ii. For long term stays in space, it will be most important to prevent changes grouped into the last category

B. Health Maintenance

1. Monitoring

a. Emphasis will be placed on providing timely warning of developing problems to allow time for preventive care

i. Pathology - strategies should be implemented to detect infectious agents before any or all of the crew become ill

ii. Toxicology - detection of toxins produced by CELSS or station components would allow prevention of further exposure

iii. Radiation - determination of exposure levels and monitoring health effects will provide necessary information to make decisions on further allowable exposures for individual crew members

iv. Metabolism - interaction with CELSS to monitor adequate nutritional intake

v. Physiology - considering the effects of microgravity, it will be important to monitor physiological changes (e.g., muscle deterioration, cardiovascular deconditioning, etc.)_

b. Monitoring strategies

i. Frequent analyses of crew urine and feces

ii. Dosimeters to monitor radiation

iii. Infrequent blood samples

iv. Physiological testing (e.g., strength, endurance, cardiovascular fitness)

2. Protocols for health maintenance

a. Exercise

i. Exercise can prevent and reverse degenerative effects of microgravity

ii. Equipment selected should be based on LEO experience
   - equipment should be efficient (i.e., produce desired effects

with minimal time spent on activity)
- equipment should be versatile (i.e., allow the crew to decide the best types of exercises)
- provide exercise facility as enjoyable to use as possible (aerobics)

b. Pharmacological Interventions
   i. Certain drugs might be able to prevent undesirable effects of microgravity (e.g., clodronate disodium has potential in preventing bone calcium loss)
   ii. Hormone interventions also might be useful in preventing deterioration of muscles and bones
   iii. As with exercise, it is anticipated that LEO experience will be valuable

c. Nutrition
   i. nutrition should be optimized based on CELSS capabilities
      - monitoring can provide feedback
   ii. dietary supplements, such as calcium might be useful

d. Gravity supplements
   i. Temporary stays in the gravity module should significantly reduce problems of microgravity
   ii. Individuals showing excessive deterioration not responding to other protocols could spend extra time in gravitational field
   iii. Routine episodes spent in gravity module (e.g., 2 days every 2 weeks) might be desirable (both physiologically and psychologically)

C. Emergency Medicine

1. Extensive equipment should be included that effectively duplicates (on a small scale) a hospital emergency ward

2. Medical ward would be located in the gravity module
   a. Special microgravity equipment would not be necessary
   b. Recovery for some injuries (e.g. bone breaks) might be improved in a gravitational field
   c. Crew member with infectious illness can be isolated away from main station and remaining crew

D. Gravitational Module

1. Design of gravity system
   a. System will have variable radius (15-30m) and variable spin rate (0-5rpm) for research and optimization purposes
   b. Two modules will be included initially expandable to four or more
   c. System can be spun up or spun down at any time and docked with the main station - counter spun wheel will provide mechanism for convenient spin up and spin down

2. Gravity system will have many uses
   a. Health maintenance - physiological and psychological benefits as discussed above
   b. Emergency medicine - use of standard equipment, etc. as discussed above
   c. CELSS - some organisms might have critical development phases requiring gravity to grow, some might grow faster, etc.

d. Research
   i. variable spin radius allows for testing many different gravity environments on such things as
      - embryology
      - CELSS components
      - physiological responses in space
      - interactions with radiation
      - etc.
   ii. gravity module would provide a good location to keep plants and animals used in life science research
   iii. testing facility for long range missions using artificial gravity

e. Readaptation and quarantine - provide facility for returning missions from deep space to quarantine crew and help them readapt to partial gravity prior to return to earth
   i. vacation area for crew members

IV. Psychological Considerations

A. Introduction
   1. good psychological state leads to higher productivity, creativity, good crew interactions, etc.
   2. poor psychological state may lead to loss of motivation, poor health, problems at home and with crew interactions, etc.

B. Sources of problems
   1. lonliness - 6 month rotation periods isolated from friends and family may lead to feelings of loss of control over situations at home. Lonliness may be exacerbated by extreme distance from home
   2. stress - there are many potential sources of stress on station :
      a. personality conflicts with crew members
      b. inability to get away from the job
      c. lack of variety in diet, recreation, job, etc.
      d. frustrations from equipment failures, bad data, etc.
   3. boredom

C. Possible preventive measures
   1. Design of living spaces
      a. modularity of furnishings
      b. flexibility in textures, colors
      c. acoustical privacy
      d. personal control of lighting, temperature
      e. private communications capability
      f. "HAL" pc
      g. individual quarters
      h. room for personal possesions such as musical instruments, artist tools, posters/artwork, etc.
   2. Design of work spaces/schedules
      a. modular - can be rearranged according to need
      b. flexibility in crew schedules
      c. separation of work and living environments
      d. variety of responsibilities
   3. Communications
      a. open access to home
      b. provide private communications quarters and group rooms
      c. video communication
      d. electronic mail

4. Preparation
    a. train crew together initially - assess potential problems before mission
5. Leisure/recreation
    a. library/quiet area
    b. microgravity, 3-D game rooms (hangar, halls)
    c. velcro darts, magnetic pool tables
    d. music, movies, home "video" movies
    e. use of tools and equipment for hobby work - additional use of spare parts for creative inventions or retrofits to game rooms, personal quarters, etc.
    f. allow ability to prepare meals
6. Health maintenance
    a. one crew member should be a physician
    b. gym equipment
    c. flexibility in health/exercise routine - provide ability to devise individual equipment (use of large hangar spaces, etc.)

D. Possible solutions to problems
1. artificial gravity environment
2. on-board "vacation" - days or week off

V. Conclusions

A. Summary of GEO habitation
1. Holistic habitation - This summary will emphasize the underlying theme of a space station crew which will be doing much more than just surviving. Crew members are living and working in relatively spacious quarters. They are actively involved in diverse, intellectually stimulating activities, with plenty of time left for privacy, recreation, sleep, etc... CELSS derived food is very palatable and the diet has variety.

B. The future of the GEO station
1. Expansion
    a. It is envisioned that 5 years following the initial launch date of 2005, the crew size will be increased to 15-20 members. Station size will be increased accordingly by adding more cylindrical habitation modules.
2. Emphases
    a. after 5 years in orbit, it might be expected that survival activities and satellite repair will level off and that manufacturing (for staging purposes) and scientific activities will increase.
3. Staging Site
    a. after more than 5 years in GSO, many of the technologies developed on the station, such as CELSS, will be ready for use on deep space missions. Station could serve as a "parking lot/garage" for deep space vehicles, as a gravity readaptation stop, etc. Also, potential will exist for mobility of the GEO space station, or a GEO clone.

Automation and Robotics

Two types of robotics systems have already been tested in the space environment: the Canadian robotic arm and the manned maneuvering unit (MMU). Both units are essential elements of the space shuttle but both are intimately dependent upon human control and decision making. Such human interactions with automated and robotic systems are likely to persist but in the presence of ever sophisticated hardware. Undoubtedly, GEO will be one of the major sites in the future for the creation of innovative automated, robotic systems.

In the envisioned CELSS operations it will be necessary to monitor the gas accumulations aboard GEO. To maintain an appropriate atmosphere these monitors will automatically seed growth reactors with nitrogen fixing organisms when the nitrogen levels are too high. At the same time the nitrogen enriched atmosphere can be pumped into storage for growth reactor use while simultaneously the atmosphere is replaced with stored gases of more appropriate concentrations. All of this activity would require little human intervention. Unicellular harvests can be accomplished continuously through the use of fluid pumps creating centrifugal forces for both pressure and density separation needs. Monitors of reactor turbidity levels will signal the automated removal of cells for storage and subsequent processing. Processing will involve either entry into food preparation equipment or re-entry into the food chain of higher biological plants and organisms. Again, little human intervention is necessary except in the user decision of what types of food ultimately are to be consumed and when. These user requests can be automatically translated into CELSS controls.

In the work module and repair bays of GEO, satellite repair and refurbishing can be aided by robotic assembly, machining, processing and handling. In addition, an automated facility for the production of VLSI circuits can permit extensive hardware updating. These capabilities will be the predecessors to the eventual creation of new space structures and vehicles.

A prerequisite to satellite repair and rebuilding is the capture or recovery of the satellites. For this purpose an orbital maneuvering vehicle with telepresent operators aboard GEO will be used. To alleviate capture difficulties a "purse" net will be used to pick up a variety of satellites and to recover other space debris in geosynchronous orbit. The OMV will direct net placement and will provide towing both to the work bays and back to the desired operational orbit. Redundant hardware will be stripped from the satellites and will be used for other purposes since neither propulsion nor gravity hardware will be needed in the continued operation of these satellites.

The station keeping needs will be assigned to flat robotic mechanisms that are capable of servicing the outside elements of GEO. Designated GEO slugs for the slow crawling nature of the motions of these robots, these devices will repair meteoroid damage, add new solar collector elements, and in higher forms will create new station infrastructure as well as new generation space vehicles.

Overall then, the envisioned systems will include automation aboard, remote robotics and station keeping robotic slugs. Each of these systems will evolve as GEO matures and develops.

Automation Application

I. CELSS Control System

1. Expert, learning computer systems

   a. routine control :
   In routine control situations, those which the computer can rectify without human assistance and/or noncritical situations, the computer would sense and correct a mass flow excess or deficit. For example, if the oxygen content of air to the human environment registered low, the computer would direct oxygen enriched air from storage tanks to bring the oxygen content to a pre-specified level.

   b. emergency control :
   In the case of a critical situation, either sudden or slowly deteriorating in nature, the computer would react in accordance with its' mathematical model of the situation. In the case of a toxin build-up above acceptable levels, it might prepare to rotate crops, but wait for a human directive before taking action. In the event of detecting a pathogen in human feces, for example, immediate and strident notice to the crew would be given, and system sterilization upon human "ok" might begin.

   c. a learing computer :
   Ideally, the system utilized would be capable of synthesizing the data gathered and resulting scenarios into a series of cause and effect pairs. This new information about the system would then be utilized to supplement and refine the computers model of the CELSS system.

2. Monitoring Capabilities

   a. chemical monitoring :
   all significant substance concentrations will have to be monitored between all processes. At present, this seems most feasible with spectrometer devises.

   b. storage monitoring :
   all storage levels must be monitored. For gases, pressure gauges may suffice; for solids such as food, electrical level sensors are feasible.

   c. biological monitoring :
   monitoring for pathogens and other harmful life is essential. This could be accomplished automatically through simple robotics utilizing culture dishes. Robotics could also be used to sample the crew feces and urine, and relieving them of this unpleasant task.

3. Robotics in CELSS
   a. harvesting :
      robotics could be used to harvest the algae after separation by centrifugation. It would also conserve labor in planting, care and harvesting of higher plants.
   b. food processing :
      robotics would be useful to automate, as completely as possible, the food processing
   c. storage and transfer :
      non-fluid substances, such as solid food stuffs, may require transportation via simple robots where conveyer belt systems are not feasible, such as within the storage bay. A robot here would ensure space-efficient storage and proper rotation of stored foods.

System Automation and Robotics

1. Major Task Assignments

A) Internal environmental controls: atmospheric controls, thermal regulation, solar collector orientation, heat radiator control, power monitoring and distribution, communications routing, radiation monitoring, fluid management, and customized crew quarters controls.

i) specialized sensors and system node monitors
ii) subsystem control models, permissive operation criteria
iii) executive intervention by human operators; system update, control methods, projections of control modifications and implementations, system history and projection of special demands
iv) ultimate use of self-modifying/learning control systems

B) External station controls: operation of plasma shield, detection of meteoroid strikes, active vibration control, solar activity monitors, free-flyer monitoring, space debris monitoring, laser orientation for light channel link to antennae farm, science and technology user needs, biomedical system monitoring via telemetry, fuel storage, handling of free flyers, transport systems from hangar to work bay or machine shop.

i) sensors and automated reactive controls
ii) system models and telepresence system monitors to "bootstrap" new system predictions for evolved structures
iii) external robotic operators for data gathering, control and modifications/repairs; new fabrications

C) Specialty systems: CELSS. Automated operation of life support, bioreactors, waste collection, protein-carbohydrate-fat extraction and storage, analysis and automated inoculation with appropriate organism, pressurized storage of oxygen or nitrogen or carbon dioxide enriched gases, subsequent automated mixing of gases for the bioreactors or station atmosphere, collection of potable water from fuel cells daily, continuous monitoring of active/stored biomass ratios, and automated set up of food processing.

i) gas chromatographic analysis of the total element reserves in each habitation phase of the station (atmosphere, food, waste and storage) to assure system balance; parallel bioreactor system allows reactor shutdown for cleaning and sterilization; each step readily automated with existing technology

ii) contingent upon cellular reactor efficiencies, automated hydroponic growth of higher plants can be encouraged and more complex bioreactor uses can include edible arthropods and fishes raised as meal enrichments; the processing of the plants and animals will call for the homogenization of byproducts for CELSS reinsertion; each of these steps can be fully automated

iii) using "match-to-sample" data comparisons with computer-generated data, warnings can be provided to gain crew intervention if the mismatches are either too large or too numerous

iv) fuel cell use in the total power needs of the station will depend on pure water needs and will be controlled accordingly except during station shadow periods when automated switching to power priority occurs

v) in view of the rapid progress in genetic engineering of single cell organisms, the bioreactors and other components of the CELSS system should be capable of large modifications to accept new organisms and very different culture needs

D) Specialty needs: Satellite services. Remote localization of satellites must be supplemented by visualization and space debris calls for similar direct visualization capabilities, a telepresence "scout" OMV of very small size would save valuable propulsion fuels and would be less likely to become a target for wandering debris; a satellite "tug" in contrast would have appropiate size and capturing devices to recover and return any satellite requiring service - once the satellite has been positively identified. When returned to the station a robotic hangar tender would place the satellite in a berth where disassembly of some components for scrutiny in the work bay will be possible and where machine/electronics needs can be determined. The automated machining and VLSI capabilities will call for crew set up time but will otherwise be fully automated. Since reassembly is largely a matter of retracing the original disassembly steps, most of the process can be readily automated.

i) need design of on-orbit scout OMV; efficient propulsion system, high resolution, binocular sight system via charged array video cameras, lightweight net capture system for clearing small debris

ii) design of on-orbit tug to be used either as a solo flight device or in concert with the scout at the recovery site; net or more specific capture system (determined by scout information) and heavy-duty hangar receiving connectors; heavy duty propulsion system and orbit reinsertion hardware; all these mechanisms prevent need for EVA around the station in the high radiation area

iii) hangar area arranged to receive satellite equipment via rails that switch the equipment to a berth position that is scaled to the appropriate size with perimeter mounted robotic arms and mechanical tool manipulators (modest 4 degrees of freedom motion) coupled with storage (cargo) nets for disassembled hardware. The manual procedures can be mimicked by computerized motion simulators for most of the reassembly.

iv) the service bay will handle more specialized disassembly and testing chores with 6 degree of freedom manipulators as well as autoranging, autonomous diagnostic and testing hardware for the testing of electronic competency. The work bay will be designed to handle direct (and coded, proprietary) telecommunications and will allow nearly automated repairs from Earth once the hardware has been appropriately aligned by a member of the crew. At any time, a crew member could be summoned to care for any difficulties the remote teleoperator could not handle.

v) substantive repairs on-orbit could be handled by the machine or electronics shops; meteoroid damage, launch ruptures etc. could be repaired or a new component could be constructed and installed through designs transmitted from Earth to robotic lathes, milling machines etc.; in the same way electronic components could be fabricated, more than likely, for equipment updating and for electronics hardening (using gallium arsenide). A VLSI lab would be easily arranged to fully protect circuit design and other information that users might consider sensitive.

vi) in each of the above instances it is envisioned that automated and robotic alternatives will arise; the facilities will be developed to the point of fostering innovative new construction on-orbit complete with state-of-the-art hardware, electronics, life support, and biomedicine. Since many users may wish to use the convenience of the antennae farm associated with GEO, much satellite hardware will be available for salvage and innovative new structures. Since all refurbishing will occur on-orbit it is likely that much of the existing equipment and material on satellites can be stripped for other uses; the stripping would be desired since orbital reinsertion activities would be acting upon smaller masses and less propulsion fuel would be consumed.

E) Specialty needs: Biomedical. It is clear that exercise can be a very time consuming activity for crew personnel in a microgravity environment, so automated systems must be arranged to allow realistic amounts and qualities of exercise. Magnetic mesh suits could be worn and controlled in such a way as to simulate dynamic resistance work via computer directed muscle loading; the aerobics could be accomplished through a wide range of exercises done in the shelter and size of the hangar and work bay spaces. It is envisioned that a wide range of microgravity games could be arranged and that robotic devices could be involved, for example, in a three dimensional form of human pinball. Should the need arise, the artificial gravity module could be required for certain amounts of time and at certain intervals for each crew person. Since the gravity module would have the communications and high technology devices common to the station, the activity of the crew in the gravity module could be a creative retreat opportunity for both mind and body.

i) need gravity suit design that simulates both isometric and isotonic exercises as well as dynamic loading exercises; in an appropriate EMF area a computer that would alter the field could assure "normal" amounts of muscle and cardiovascular loads as well as stimulation of venous recirculation and lymphatic returns

ii) design of aerobic games package for large spaces and automated monitoring of the pulmonary and cardiovascular effects

iii) provision for individual and personal facilities in the gravity module, provide temporary isolation from the demands of the station, and provide for maximum opportunities at exercise for both body and mind

2. Major Innovation Needs

A) Development of AI into a user friendly assist capacity
B) Electrostrictive operations of manipulators; bio-composite materials
C) Development of better optical and integrative load sensors
D) Development of conservative propulsions systems (reclamation)

3. Automation and robotics will be subjugated to crew personnel use and the activities will provide user friendly models for Earth applicationns

A) Either or arguments will be minimized through "cooperation" models of automation and robotics use.
B) Better natural-machine language communications
C) Wider range of motion kinematics for robotics
D) Better computer vision and pattern recognition
E) Cost benefit analyses that fully contrast automated versus manned activities should show that a combined man-robot activity is the most effective and most efficient approach to space exploration and utilization.

GEO STATION SYSTEM OVERLAPS

I. Power Systems
   A) Backside of solar cell array could be covered with "chevrons" and used for heat dissipation.
   B) Solar cell array can be used to shadow the space station in order to cool it.
   C) Fuel cells used for energy storage could be incorporated into an electrolysis water purification system for CELSS. Oxygen fuel stores could also be used in the control of cabin atmosphere.
   D) Energy given off during waste disposal processes can be "extracted" and stored in fuel cells.
   E) O_2 stores for fuel cells may also be used as an O_2 source during emergency medicine.
   F) Since fuel cells produce H_2) from molecular O_2 and H_2, drinking water would be more psychologically drinkable.
   G) Power systems would have to be maintained and controlled by robotics and AI.

II. Shielding
   A) Meteoroid shielding can also serve as bulk radiation shielding.
   B) An emergency radiation bunker, for use during periods of elevated radiation fluxes, could be surrounded by CELSS H_2O stores for additional protection.
   C) Radiation shielding on rotation module should be manipulatable in order to study the effects of GEO radiation on experimental plant and animal life.
   D) Station modularity, necessary to minimize damages done by impacting meteoroids, has beneficial consequences from both construction and psychological standpoints.
   E) Shields will be maintained primarily with robotic systems.

III. Thermal Control
   A) Heat management, i.e., buffering, transport, etc. ..., could be achieved using CELSS water stores.

IV. CELSS System
   A) Crew food source could be supplemented with plants and animals used in experimental rotation module.
   B) The effectiveness of CELSS crop rotation schedules could be partially monitored with indicators of crew health and physiology.
   C) In addition to being necessary for continuous food production, crop rotation would allow crew members some control over diet changes and would also involve them in the plant growth and harvesting processes.
   D) Microorganisms used in CELSS as food source could also be used in various manufacturing processes.
   E) Many aspects of the CELSS unit will be monitored and controlled with robotics and AI.

V. Biomedical/Experimental

A) Health maintenance and emergency medicine may, if necessary, be achieved in the gravitation module.

B) Experimental gravitation module can also be used in "reconditioning" deep space travelers before return to earth.

VI. Other

A) Large hangers used for satellite repair and storage may also be used as large exercise areas (zero-g gymnasium).

B) Personal communication systems are useful for:

I) transfer of proprietary information (business)

II) communication with family and friends (psychologically important)

III) serve as part of a personal computer system to be used as a private work station, library, etc.

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